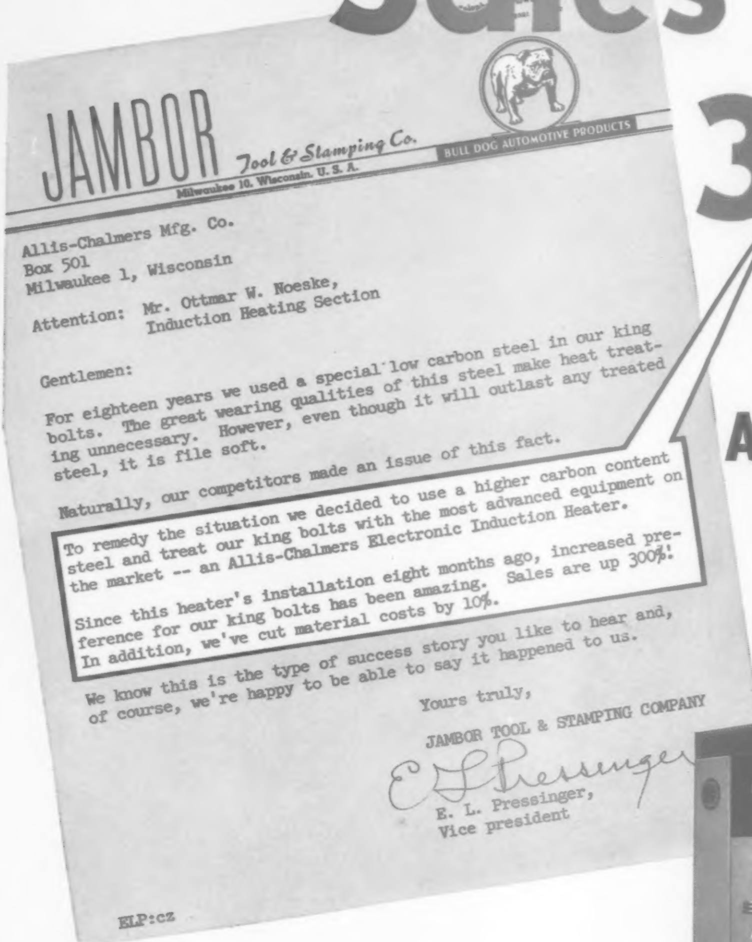
ALLIS-CHALMERS Electrical REVIEW

3RD QUARTER 1955

HEAT TREATING BOOSTS PRODUCT PREFERENCE

Sales Up 300%



JAMBOR Tool & Stamping Co.
Milwaukee 10, Wisconsin, U. S. A.
BULL DOG AUTOMOTIVE PRODUCTS

Allis-Chalmers Mfg. Co.
Box 501
Milwaukee 1, Wisconsin

Attention: Mr. Ottmar W. Noeske,
Induction Heating Section

Gentlemen:

For eighteen years we used a special low carbon steel in our king bolts. The great wearing qualities of this steel make heat treating unnecessary. However, even though it will outlast any treated steel, it is file soft.

Naturally, our competitors made an issue of this fact.

To remedy the situation we decided to use a higher carbon content steel and treat our king bolts with the most advanced equipment on the market -- an Allis-Chalmers Electronic Induction Heater.

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Yours truly,

JAMBOR TOOL & STAMPING COMPANY

E. L. Pressinger

E. L. Pressinger,
Vice president

ELP:cz

...increase credited to ALLIS-CHALMERS INDUCTION HEATING

Jambor reports selective control of hardening and penetration with their 20-kw Allis-Chalmers heater. White line indicates hardened steel. Black area around it is merely plastic wrapping to increase visibility of etched surface.

If your production involves hardening, soldering, annealing, brazing and/or heating — find out about Allis-Chalmers induction heating. See how you can increase preference for your products, boost output, decrease costs and cut rejects.

Get productive flexibility, too. Setting up these heaters to handle various jobs is merely a matter of changing a single coil. You can handle small, odd-lot work with almost as much efficiency as long production runs.

For all the facts, contact your nearest A-C District Office or write Allis-Chalmers, Milwaukee 1, Wisconsin.

A-4501

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ALLIS-CHALMERS Electrical REVIEW

THE COVER

HIGH SPEED PHOTOGRAPHY records the performance of this all-new 600-volt, 50,000-ampere interrupting capacity breaker in one of a series of progressive tests made at increasing currents through rated capacity to destruction. In verifying the function of component parts from arc propagation to arc interruption, high speed photography played a vital part in the design of this line of low voltage breakers which are described in an article starting on page 4.

Cover and center spread
A-C staff photos by M. Durante

Allis-Chalmers
ELECTRICAL REVIEW
Vol. XX No. 3

Issued quarterly. Subscription rates: U. S., Mexico, and Canada, $2.00 per year; other countries, $3.00; single copies, $1.00 in advance.

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Indexed regularly by Engineering Index, Inc.
Allis-Chalmers ELECTRICAL REVIEW is available to public and institutional libraries on microfilm from University Microfilms, 313 N. First St., Ann Arbor, Mich.

Address Allis-Chalmers Electrical Review, Milwaukee 1, Wisconsin

Printed in U. S. A.

BREAKER DESIGN...

12,500 amperes per cubic foot

by O. J. ALBANI
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DESIGNING a line of modern air circuit breakers from beginning to end is an interesting and intriguing project. In fact it is an excellent example of the kind of problems handled by a design group in the heavy electrical equipment field. While the job is primarily an electrical engineering project, many of the toughest problems were those in the realm of the mechanical engineer, with a formidable supply of metallurgical and some hydraulic obstacles thrown in.

The design described here is that of the 25,000-ampere breaker in a coordinated line of 600-volt, three-phase air circuit breakers with interrupting capacities rated 15,000, 25,000, 50,000, 75,000, and 100,000 amperes with corresponding continuous current ratings of 225, 600, 1600, 3000, and 4000 amperes, respectively.

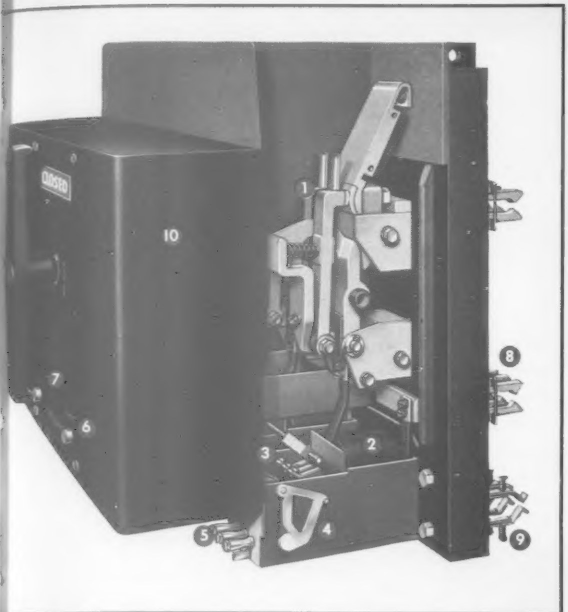
Standards determine starting point

The Large Air Circuit Breaker Standards published by AIEE, ASA, and NEMA may be considered as the starting point, since they prescribe the minimum electrical and mechanical requirements which must be met. Like most circuit breaker standards, these standards go into considerable detail (about 11 pages in the current issue) in specifying both performance and manufacturing limits. Provision must be made, too, for any anticipated changes in future standards.

Like any other piece of industrial electrical equipment, manufacturing cost for a low voltage circuit breaker must be kept low enough to sell the unit. (A typical 25,000-ampere breaker without auxiliaries must sell in the $500 range to be competitive.) Making all the breakers in the industry would hardly justify tooling on a Detroit level.

Space sets the pace

Probably the most severe limits the designs must meet are those of space. The 25,000-ampere units must mount four high in a standard switchgear cubicle 18″ wide, 54″ deep, and 92″ high. After necessary clearances, space required for buswork in the rear of cubicle, etc., this leaves maximum overall dimensions of about 18″ deep x 19″ high x 13″ wide for a complete breaker, including projecting operating handle in front and disconnect devices in the rear. Assuming the disconnect devices and handle must both project beyond the "working" portion of the breaker leaves a space 14″ deep. Into this volume of 2 cu. ft. must now be put a three-phase breaker, mechanically trip-free, with operating mechanism, arc chutes, three individual trip coils capable of carrying full overload, three adjustable tripping assemblies, and up to six time delay mechanisms. Then space and mounting arrangements must be provided for mounting at least all of these optional accessories: thermal magnetic trip mechanisms, two sets of ganged auxiliary switches, indicating lights, bell alarm switch, undervoltage trip coils, remote electrical tripping solenoid, mechanical lockout protection, auxiliary X and Y relays and a closing solenoid!



IMPROVEMENTS IN DESIGN and construction of new low voltage breakers are shown. 1. Individual forged alloy blow-on contacts. 2. Completely insulated thru-current trip coil. 3. Sealed time-delay devices. 4. Faulted phase targets. 5. Calibrated tripping device adjustment. 6. Trip button. 7. Reset button. 8. Primary disconnects. 9. Secondary disconnects. 10. Dead-front shield. **(FIGURE 1)**

Maintenance (or lack of it)

The low voltage breakers unlike their big brother, the 4.16-kv magnetic air breakers, which roll on their own wheels into roomy individual switchgear cubicles, can expect no tender, loving care. Many locations in which the breakers serve will be ill-equipped for even the minimum of maintenance. Lubrication must not be essential to the breaker operation. Dust, moisture, occasional corrosive fumes will all be part of the working conditions. Yet, after performing thousands of operations at full load without attention for months at a time, the breaker can expect to have to open suddenly against all of the power that surges over an industrial feeder circuit under full short-circuit conditions.

Design objectives offer challenge

All of the design objectives for an entire line of breakers would make a lengthy list. Certain particular goals were considered essential or at least desirable, yet they were not involved in the standards, maintenance, space, or economic limitations mentioned. A few of them are of particular interest:

1. First of all, experience with other equipment had shown the advantages of the blow-on contact structure. This would necessitate a more elaborate moving contact assembly but would provide far more dependable electrical performance.

2. It was decided that "dead front" construction would be worth considerable effort if it could be achieved. Insulating or shielding all live parts would eliminate any hazard to operating and maintenance personnel.

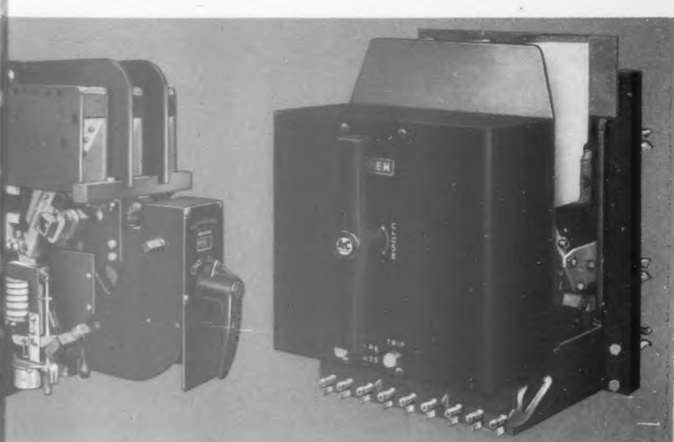
3. Maximum interchangeability through the use of fewer parts in each breaker and the use of the same parts in different ratings of breakers would be a big advantage. It had to be weighed against any possible sacrifice in performance or economy, of course.

4. Improved design and performance over previous time delay and overcurrent trip mechanisms was essential. Any time delay apparatus should remain in permanent adjustment and be essentially unaffected by temperature, lack of maintenance, age, or length of time in service. All three tripping functions — instantaneous, short time, and long time — ought to be independently adjustable without changing parts.

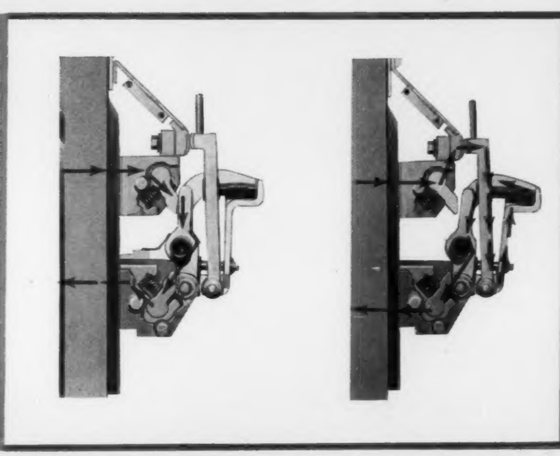
Final design incorporates new solutions

About three years elapsed between the time the design objectives were set down and the date the first successful pilot model was available for test. In that time dozens of promising designs had to be discarded for one reason or another. An analysis of the final breaker design makes an interesting study.

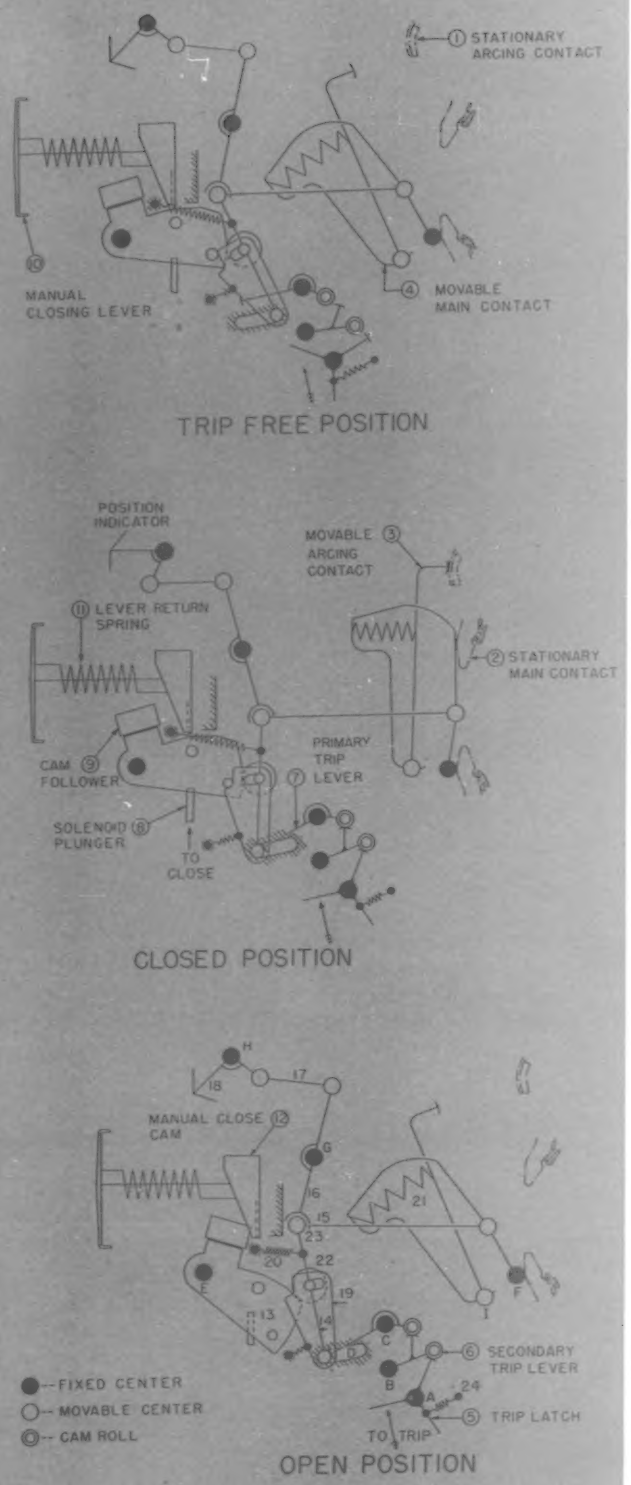
The final design of the contact structure is shown in Figures 3a and 3b. The assembly, which includes both main and arcing contacts, includes several improvements over previous designs.



IMPROVEMENTS IN DESIGN of the new 25,000-ampere breaker are apparent in this comparative view. Old design was actually 24½" high compared to 19" for the new. In spite of reduced size, new breaker has a superior electrical and mechanical performance and numerous improvements in design of components. Many components in new design are interchangeable over wide range of ratings. **(FIGURES 2a and 2b)**



CURRENT PATHS in normal operation (left) and during initial stages of opening or closing (right). Note how current flows through contact blocks to contact fingers, then to contact arm. Resulting forces tend to blow loop open, forcing fingers against contact arm. At opening or closing, arcing contacts are held closed by reverse current loop until main contact travel is complete. **(FIGURES 3a and 3b)**



OPERATING MECHANISM is shown in simplified form in all three positions. Note that in trip-free position it is impossible to hold breaker closed with closing lever. Several hundred pounds of contact arm pressure is triggered with a few ounces of thrust on the trip latch. Stainless steel pins and needle bearings are used to reduce friction. (FIGURES 4a, 4b, 4c)

Contact structure utilizes magnetic forces

The stationary contacts, both main and arcing, are positioned so as to provide positive wiping action both in opening and closing, thus insuring clean, low resistance contact surfaces throughout the life of the breaker. The stationary main contacts pivot in the mounting socket provided in the upper contact block and give a positive wiping action at all contact points, insuring high conductivity. A wiping high pressure contact is achieved by an eccentric configuration on the lower end of the movable main contact element. The lower contacts are in continuous contact and take no part in the interrupting sequence of the breaker. No flexing pigtail conductors are required.

The contact structure, both arcing and main, has been arranged to utilize the inherent magnetic forces in holding the contacts firmly together during current surges. The dominating thrust of the natural magnetic fields is always in a direction to aid the compression springs in maintaining contact pressures.

During breaker opening or closing, the current flowing through the arcing contacts forms a reverse current loop which is superimposed on the simple direct loop. See Figure 3b. The path and size of this reversed loop opposes and more than compensates for the direct loop magnetic effect. The magnetic forces and the spring forces combine to produce a "blow-on" effect on the arcing contacts.

With the breaker in the closed position, as in Figure 3a, the current flows through the main contacts in a direct simple loop. The spring-backed bridging contacts are located on the inside of the corners of the loop, so that the magnetic forces and spring forces combine to eliminate premature or uncontrolled parting. The contact arms, of course, are held closed under several hundred pounds' pressure from the operating mechanism.

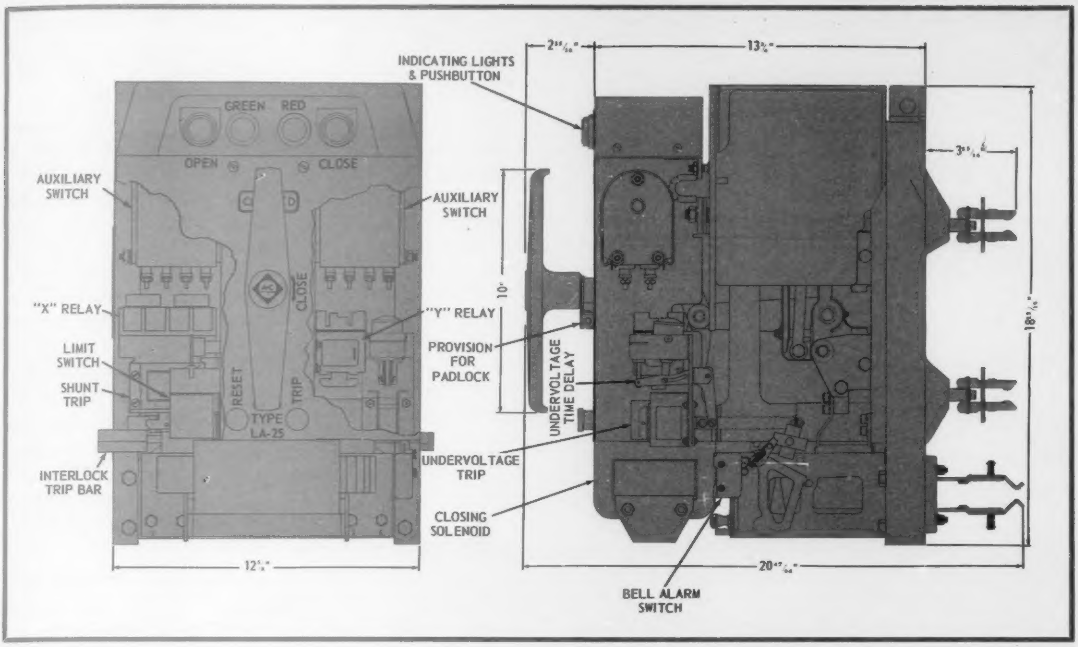
Maximum arcing contact life has been obtained through the use of silver tungsten alloys. Main contact surfaces are of silver for high conductivity.

Arc chute has slotted splitter

The arc chute for the 25,000 ampere breaker is a simple all-molded structure of cement asbestos having no metal components. It provides a high arc erosion resistant enclosure over the upper portion of the contact assembly which serves as the arcing chamber when the arc is initially drawn. Progression of the arc upward on the stationary arc runner and the rod-like tip on the moving arcing contact carries it into the interrupter portion of the arc chute. This rod-like tip on the movable arcing contact serves as a moving runner allowing immediate transfer of the initial arc from the contact face up into the interrupter portion of the chute. A slotted intermediate splitter in the upper portion of the chute provides an increasing cooling effect, giving efficient and rapid extinction for the full range of current magnitudes.

Operating mechanism has little friction

One of the principal objectives achieved in the new design was a reduction in size of the breaker. Perhaps the greatest contribution to this reduction in size resulted from the smaller mechanism. To accomplish this, mechanism pins



OVERALL DIMENSIONS and mounting position of many of the optional pieces of equipment are shown. Most of the optional equipment is interchangeable with other ratings of breakers in the same series.

Unusual feature of the 50,000-ampere breaker is a fast-acting electrically operated hydraulic closing mechanism. Volume of "working" parts of breaker shown is approximately two cubic feet. (FIGS. 5a and 5b)

and latches are of stainless steel and other high strength alloys. Precision castings are used to replace intricate machined parts. Because several hundred pounds of pressure must be triggered with a few ounces of thrust from the trip mechanism, friction has been reduced to a minimum through the use of prelubricated needle bearings at all critical points.

A simplified analysis of the operating mechanism in three different positions is shown in Figures 4a, 4b, and 4c. The principal components include a closing cam, which is rotated either manually or electrically, a floating linkage that varies its fixed center on opening or closing, and a load-reducing latching scheme. It is impossible to engage the closing mechanism so long as any of the tripping means are in control.

In contrast to previous breakers the new unit uses a T-handle for manual closing. Tests showed that it is more convenient and easier to close breakers in the top and bottom locations of the new four-high switchgear when the operator can use both hands.

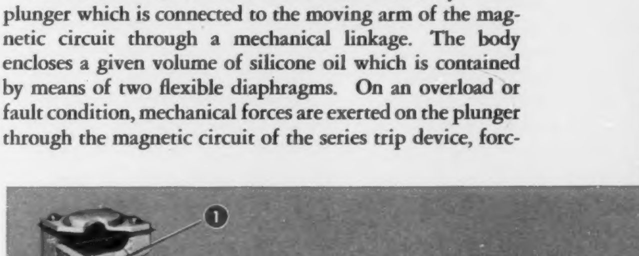
Series overcurrent trip unit is versatile

Figure 5 shows the final design of the series overcurrent trip unit. It covers the complete requirements set forth in NEMA standards, and is applicable to cascaded and selective tripping systems. The basic design of each single-phase trip unit includes a series coil, a magnetic circuit with armatures, and one or two sealed time delay devices. These individual phase overcurrent trip units are mounted on a common base.

Each single-phase overcurrent trip unit can be provided with any combination of the three trip elements — long time, short time, and instantaneous. These trip elements are separate and distinct one from the other. All the trip elements are individually adjustable over their full range of pick-up calibrations.

The long and short time delay elements are similar. Each trip element is delayed by means of a positive displacement silicone oil time delay device.

This device is constructed of a die-cast zinc body with a plunger which is connected to the moving arm of the magnetic circuit through a mechanical linkage. The body encloses a given volume of silicone oil which is contained by means of two flexible diaphragms. On an overload or fault condition, mechanical forces are exerted on the plunger through the magnetic circuit of the series trip device, forc-



OVERCURRENT TRIP AND TIME DELAY mechanisms are shown. Porous metal orifice (1) in sealed time-delay device has fixed characteristics at all normal temperatures. On overload, all three armatures (3) will tend to close against solenoid core (6) but springs (4), (5) and time lag of plungers in time-delay devices limit tripping action to appropriate tripping elements. **(FIG. 6)**

ing the plunger upward. This, in turn, forces the oil against the ball check valve which blocks the passage of oil. Thus the oil is forced through the porous bronze filter into the upper oil chamber. For any given displacement of the plunger, a definite time delay is required for the oil to pass through the filter. When the overload is removed, the plunger will reset, allowing oil to flow from the upper reservoir to the lower chamber. This flow of oil will unseat the ball check valve, allowing a quick return of the device to normal operating condition.

In manufacture, the time delay devices are evacuated and filled with oil, then sealed and calibrated. There are no adjustments to the time delay device itself for the various trip settings. Adjustment is made by means of changing the moment arm between the trip element and the time delay device. The same type of time delay device is used for both the long and short time-delay assemblies.

The silicone oil used in these time delay devices has an almost constant viscosity over a temperature range of minus 30 to a plus 150 degree centigrade range. Since it is hermetically sealed, it will be unaffected by normal atmospheric temperature and pressure variations.

This new series overcurrent trip device includes a new semaphore-type indicator on each of the phases. Operation of the trip device causes the semaphore to drop, indicating which phase or phases of the three-phase circuit caused the breaker to trip. These indicators function only on overcurrent tripping and are manually reset by a reset button. Failure to reset the indicators has no effect on either closing or subsequent tripping operations of the breaker.

Mounting base assures rigid assembly

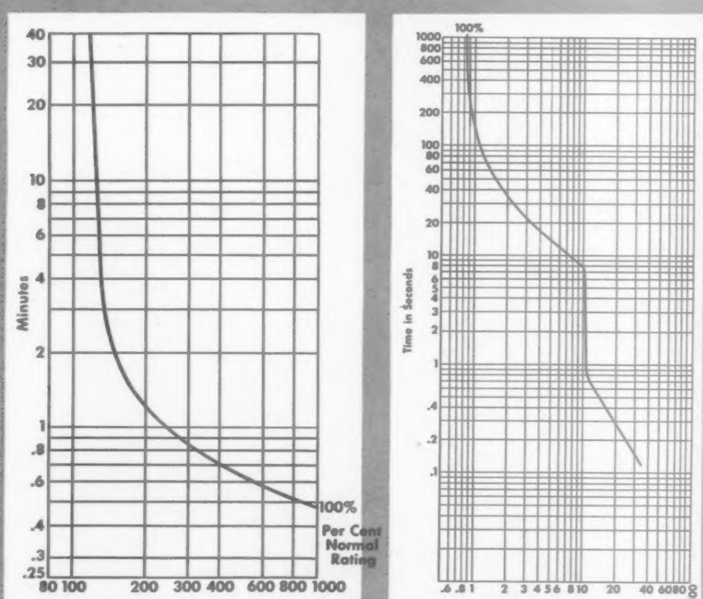
A high impact canvas bakelite molded resin was selected for the individual phase bases. This achieved maximum electrical creepage distance between phases and between phases and ground. Steel tie rods imbedded in the molded base material anchor the units together, insuring a rigid, accurate assembly.

Further reduction in the overall space requirements of the breaker was achieved by close attention to detail in the design of auxiliary attachments. These attachments along with the breaker control were located so that they are completely covered by a shroud which encloses the mechanism, forming a dead front on the breaker.

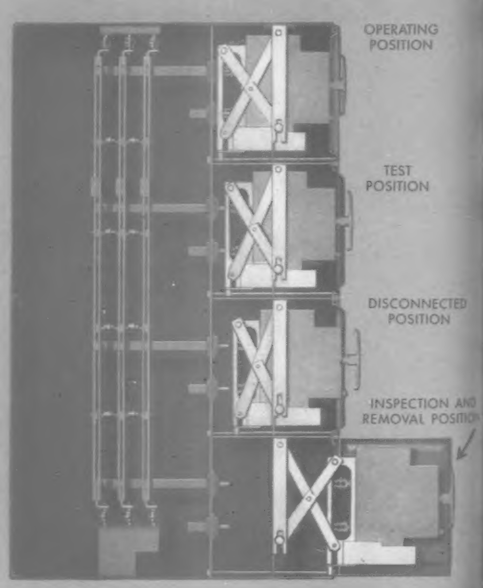
Switchgear redesign matches breaker

The switchgear in which the new breakers are mounted was also redesigned. A full discussion of that design program is beyond the scope of this article. However, some of the unusual features of the switchgear are shown in Figure 8. Note that when the breaker is in the operating position the front of the compartment is slightly recessed. If the recessed front panel is reversed, the compartment door may be closed with the breaker in the test or disconnect position. This is quite simply done and no tools are needed. This allows a de-energized breaker to be left in a protected position in a line-up of gear without reducing aisle space or trim appearance of the entire assembly.

The pantograph mounting assembly provides solid support and positive alignment for the breaker, even in removal position. It is possible to inspect and adjust, if necessary, the breaker or interlock mechanism, while the breaker is supported on the positioning mechanism.



TYPICAL THERMAL AND SELECTIVE trip curves are shown. Easily adjustable trip characteristics enable breakers to be co-ordinated with other protective equipment. Since trip device is identical for all breakers, curve is typical for all ratings. **(FIGURES 7a and 7b)**



INDOOR SWITCHGEAR of new design was designed to utilize new breakers. Four-high, 18" wide, cubicle allow breakers to be tested or disconnected without removing them. Gear features accurate, positive positioning pantograph mechanism. **(FIGURE 8)**

HERE, FOR THE FIRST TIME, an aluminum-tubed surface condenser is being installed by a utility. After several years of tests conducted on small bundles of aluminum tubes in other units operating under similar water and steam conditions, Wisconsin Electric Company is installing 17-gauge aluminum alloy tubes in this 105,000-square-foot single-pass surface condenser on the Number 3 unit of their Oak Creek plant.

POWER OF THE FUTURE

by R. C. ALLEN
Director
Mechanical Engineering
Allis-Chalmers Mfg. Co.

AN EVER-INCREASING SUPPLY of cheap and plentiful power is inseparably associated with the comforts and advantages of the American way of life. Yet our common sources of power, our everyday fuels such as coal, natural gas and petroleum, are being consumed at an alarming rate, and they are not being replaced by any natural or man-made physical or chemical cycles. Prompted by these facts, the potential capabilities of other sources of energy, such as wind power, tidal power, nuclear energy and solar energy, are now being studied to a far greater extent than ever before by scientists and engineers who are now much better equipped with scientific background data for such research than in the past.

Power generation statistics show that our country has the largest total capacity for electric power generation and very nearly the greatest installed capacity per capita of any nation in the world. Consequently, we also consume more fuel than any other nation. Kilowatt-hours per capita consumed in the United States for 1954 was 2528, significant since the prosperity and productivity of a country is largely dependent upon the kilowatt-hours per person used for producing things.

Energy consumption

In 1954, the installed electric utility generating capacity in the United States reached and passed the 100,000,000 kilowatt mark. This installed capacity has been built up principally over the past seventy years. In 1902, the installed capacity totalled 1,212,000 kilowatts, and in 1925 21,472,000 kilowatts.

The present total capability in electric power generation is composed of 76 percent fuel-burning plants and 24 percent hydroelectric plants, the fuel-burning plants being further subdivided into 97 percent steam plants, 2.8 percent internal combustion engine plants, and approximately one-fourth of 1 percent gas turbine installations.

While these figures show a tremendous increase in generating capacity over the past years, the predictions now recognized by the central station industry for the next decade are equally striking. Industry estimates call for a doubling of the installed capacity of the country's central station electric generating plants by 1965, thus bringing the total central station capability to 200,000,000 kilowatts.

Great credit is due to the central station industry for its concerted attack on costs over the past half-century. The curve of average overall power costs plotted against years has shown a continuing downward trend for the first forty years of the century, with a nearly constant average over the past decade, in spite of the very substantial rising costs for labor and materials. The average unit cost of power for all classes of services has shown only a few very minor upward jumps in recent years.

Fossil fuel resources

While information about new deposits of fossil fuels being discovered seems to conflict with reports of dwindling supplies, economists of the present day base their pessimistic views on data which are immeasurably more precise than the corresponding figures reported a few decades ago.

Reports prepared by Palmer Putnam and other economic authorities indicate world supplies of fossil fuels as having an aggregate not exceeding approximately eighty "Q." The quantity "Q" is defined as an amount of fuel having a total heat content equal to 10^{18} Btu. A more convenient way of visualizing this very large number is to remember that it represents a quantity of heat equal to that which would be liberated by the combustion of forty billion tons of coal, having a calorific value of 12,500 Btu per pound.

Mr. Putnam's economic studies indicate that the world's consumption of fossil fuels up to the year 1947 was twelve "Q." His estimates indicate the annual consumption as of 1947 as 0.1 "Q."

The extension of these studies in conjunction with the Bureau of Mines has further led to a downgrading of the total resources. Of the approximately seventy "Q" now thought to represent the world's coal resources, some authorities have concluded that as little as six "Q" is the quantity which is economically recoverable. If the average rate of use for the next few decades is taken at 0.2 "Q" per year, it would appear that our supplies of high-grade fuels will be consumed in something like the next thirty years.

Studies by Dr. J. E. Hobson, Director of the Stanford Research Institute, support the views of other economists. As he points out, "The coal beds of thickest veins, of highest quality, and of greatest accessibility are being worked first — and, therefore, exhausted first. Further, it is on these same beds of bituminous coal — only a percent or two of the aggregate — that steel mills must depend for coke. And low-cost steel is only less vital to our economy than energy itself.

"When these and other realistic considerations are factored into the picture, we find that the pleasant, soothing total of coal reserves good for 2000 years has plunged to nearer 200, and for some essential coals of high quality to a matter of decades."

FALLING WATER, once the source of almost all mechanical power, now supplies only 24 percent of America's power needs, and sources for future development are limited. The Shipshaw plant of the Aluminum Company of Canada, Ltd., with 12 units of 100,000 hp each, is one of the world's largest prime mover plants. **(FIG. 1)**

With regard to the consumption of petroleum and natural gas, Dr. Hobson predicts that the time when the use of these fuels will exceed the ability of the wells to produce is within one or two dozen years.

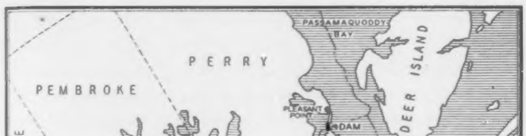
Other sources of energy

Hydroelectric power in the United States, as a source of electrical energy for future development, is also limited. While the known available sources of hydroelectric power in this country now undeveloped total around 86 million kilowatts, only about 40 million kilowatts is considered economically recoverable. At the present rate of construction, these sites will be developed within the next thirty-two years.

Power from the tides has received much consideration and detailed study. Probably the largest installation ever seriously considered was the Passamaquoddy project on the international boundary between northeastern Maine and southern Nova Scotia. Here the average tide is about 17 feet, with maximum tides in the neighborhood of 30 feet. During the nineteen thirties, the building of a power system with ten 11,000-kw generating units was considered. However, the estimated cost of the slow-speed, low-head generating machinery, together with the large number of emptying and filling gates and their controls, and the tremendous cost of the dikes to enclose the reservoirs appeared at that time to point toward an overall cost of the project which would be excessively high in relation to the corresponding investments for competitive sources of power. The project was abandoned after a limited amount of construction had been completed.

While some authorities question the commercial merit of tidal power for the immediate future, a recent press release announced approval of a substantial government appropriation to support further studies of the Passamaquoddy development.

Almost every year new proposals are made and pilot plants built for utilization of the winds as a source of power. The unit which was built at Grandpa's Knob in Vermont during the period of 1941-1945, had a two-



LARGE-SCALE TIDAL POWER developments for the generation of electricity have been considered. Dropped at an early stage as uneconomical in the middle 30's, the Passamaquoddy project, indicated above, is now being re-evaluated. **(FIGURE 2)**

bladed propeller 175 feet in diameter. A 1250-kw generator was mounted on the tower which was 120 feet above the mountain top. This unit required a 20-mile wind to generate 1000 kw.

The engineers responsible for the construction estimated that further units could be built at a cost of $191 per kilowatt of peak capacity. It was concluded that the intermittent nature of the load which could be scheduled for this unit would not warrant the investment of more than $125 per kilowatt of rated output. While for isolated and remote locations units of this type are desirable and convenient — continued recent activity in the field of large wind mills for electric power has been reported in the technical press — the large-scale application of this source of power by the utility industry is not anticipated in the immediate future.

Studies of solar heat as a source of energy are developing at an increasing tempo. The sun daily liberates tremendous quantities of heat which could be turned into useful power if an economical conversion process were found. During the sunlight hours, the sun radiates to the earth an amount of heat per acre of surface equivalent to 5470 kilowatts of electric power. This is the amount of heat reaching the outer atmosphere which envelops the earth. After deducting for transmission losses through the atmosphere, and losses in the low temperature power cycle, there appears to be a possibility of recovering approximately 220 kilowatts of electrical output per acre of exposed black body surface.

In order to equal the Port Washington steam plant of the Wisconsin Electric Power Company in which there are five 80,000-kw generating units, about 1800 acres of black absorbing surfaces, completely housed in, would be required. Pressure-tight heat-absorption boilers, a part of this installation, would probably generate steam at a pressure below 125 pounds per square inch.

Although a number of eminent scientists are somewhat more optimistic on the subject of economical power from the sun, our countryside will probably not be dotted with heat-absorbing, sun-fired boilers in the next few decades unless a highly efficient energy storage system is devised.

Nuclear energy holds promise

With the immediate present outlook for large-scale generation of electricity from wind, tidal and solar power sources somewhat discouraging — and fossil fuels rapidly being depleted — what about the future?

As a potential power source, nuclear energy holds great promise. Compared to the 70 "Q" total and only six "Q" of economically recoverable high grade coals, nuclear fission sources have a 1500 "Q" potential. This figure is based on the practical development of breeder reactors which will convert fertile material into fissionable isotopes so that all of the fertile materials, such as uranium 238 and thorium 232, may be consumed.

The 1500 "Q" potential will drop to some extent after further experience with the chemical processing of used fuel elements.

Transformation of the high energy release resulting from nuclear fission directly into electrical energy is an intriguing speculation, although a practical application of this idea has not yet been disclosed.

Scientists have collected the beta radiation from decaying isotopes on suitably insulated bodies. The resulting voltage is very high, the quantity of current extremely small. Electrostatic motors have been constructed, although these do not appear to be in a channel of practical large-scale power development. Other research has been directed toward the use of thermocouples, using the heat resulting from fission to provide the energy for the generation of direct current. The energy efficiencies of these two processes are extremely low, and neither has yet indicated promise as a means for developing the large blocks of electrical energy needed for our power lines.

According to brief press releases, promise of a new kind of electric power generation for some distant future date may take form, following advanced and highly theoretical

WIND POWER has been explored and this 1250-kw experimental unit at Grandpa's Knob supplied much valuable data. **(FIG. 3)**

STEAM TURBINES, presently supplying about 75 percent of all commercial power, depend on thermal energy derived from fossil fuels or nuclear heat sources. This tandem reheat turbine supplies 75 mw for Wisconsin Power and Light Company. **(FIG. 4)**

THERMAL ENERGY can be carried fr liquid-metal cooled reactors by pumps th have no rotating parts, such as this reve flow Einstein-Szilard pump. **(FIGURE**

studies now being conducted. Scientists believe that at temperatures above 20,000 degrees centigrade, matter is almost completely ionized, and if passed through a series of magnetic fields might be accelerated to extremely high velocities. This was mentioned by Dr. Gerhard Piel, in his presentation at MIT in 1954.

Dr. Arthur Kantrowitz, in his *Scientific American* article of September, 1954, said, ". . . at these temperatures a gas becomes a very good conductor of electricity because the heat produces a large number of free electrons. . . . Because of its high conductivity, a filament of very hot gas behaves like a wire in an electric or magnetic field. . . . It is plain that an electric current will be generated in a highly conducting gas moving across the lines of force of a magnetic field just as it is in the armature of an electric generator."

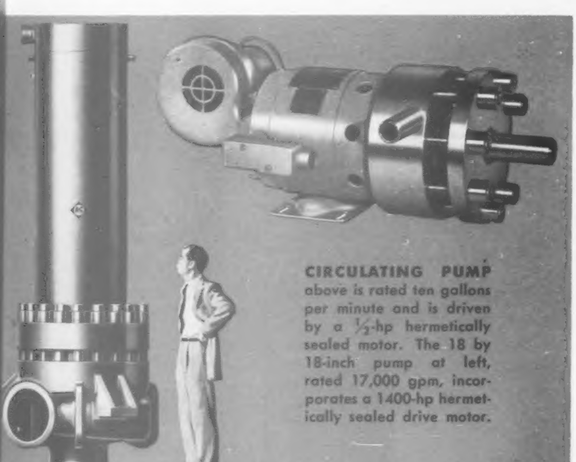
These extremely interesting and intriguing fields of investigation seem to be pointing toward new types of equipment for electric power generation. It must be recognized, however, that there is much to do before achieving the fundamental requirements necessary for such cycles, particularly with regard to the problem of containing large quantities of matter at temperatures far above the vaporization temperature of any known substance.

Atomic energy is now considered as a practical and an immediate potential source of power. The steam cycle continues to be the mainstay of the power business, just as it has been during the past century. The atomic fission plant becomes, in its most practical form, a "heat source," as the commonly applied name indicates. This calls for steam turbines of approximately conventional design for the conversion of heat energy to mechanical power.

Nuclear power plants

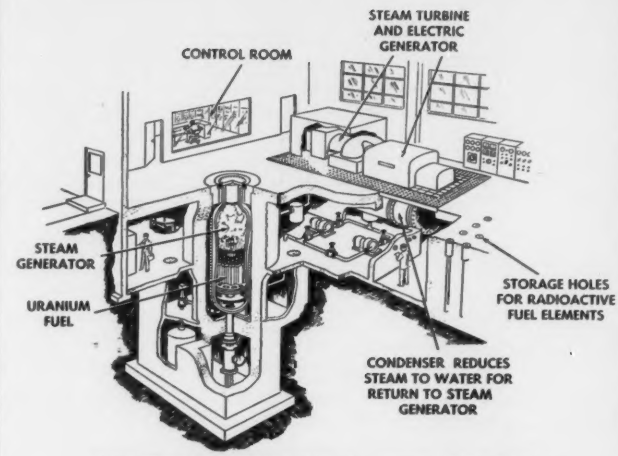
Many new types of nuclear heat source power plants are being considered, and some have been authorized for construction.

Out of the maze of conflicting information and opinions which are being advanced in the nuclear power generation



CIRCULATING PUMP above is rated ten gallons per minute and is driven by a ½-hp hermetically sealed motor. The 18 by 18-inch pump at left, rated 17,000 gpm, incorporates a 1400-hp hermetically sealed drive motor.

CENTRIFUGAL PUMPS of special design are used for circulating radioactive liquids. By hermetically sealing electrical drive-motor parts and arranging for the pumped liquid to support the bearings, leakage is eliminated. **(FIGURE 6)**



NOW UNDER CONSTRUCTION, the Argonne National Laboratory's new experimental boiling water reactor will be the heat source for a 5000-kw steam turbine generator unit. **(FIGURE 7)**

field, outstanding problems have become evident. For example:

Because of their weapons value, fissionable materials will be under government control for an indefinite future period. This is a phase of economics not found in conventional power plant operations.

The safety considerations of nuclear power plant operations are much more complex than with conventional plants. However, this phase of the problem is being effectively solved even though insurance companies have not yet developed a uniform policy for the risk coverage on utilities with this type of central station.

Nuclear heat source generating plants, on the basis of public utility operation and accounting, cannot as yet compete with modern fossil fuel-burning steam plants in locations where conventional fuel is cheap and water is plentiful. The processing of used fuel elements and the disposal of radioactive waste material are unusual problems which must be solved by further research and practical engineering and production procedures.

Despite these problems there is a great need for doing everything possible to advance the development of nuclear heat source plants because of the rate at which we are nearing the end of our rich store of fossil fuels.

The most common fuel for a nuclear power plant is uranium 235, which occurs to the extent of only seven-tenths of 1 percent of the mass of natural uranium. Uranium 235 is the only fissionable isotope which is found in nature. A practical reactor can be constructed with natural uranium as fuel; however, for some applications, the size and cost would not be consistent with the present-day economies of power plant construction. Commercial considerations in some cases may require the use of enriched fuel even though the fuel itself is inherently more costly.

In the most commonly employed thermal reactor system, the moderator, which might be graphite, slows the neutrons down to the most effective energy level at which fission can be promoted to support a chain reaction. After

operating for a period of time, the fuel elements must be processed to remove undesirable isotopes that have built up during the fission process. If not removed, the formation of isotopes would retard and ultimately stop the chain reaction. The unused uranium fuel can be chemically separated and used again in new fuel elements.

In one phase of reactor operation, uranium 238, a material that does not generally fission under reactor conditions, becomes converted in a small degree to the fissionable element plutonium.

In the breeder reactor, the amount of plutonium produced is greater than the amount of fissionable fuel which is consumed. This type of reactor is under commercial development and has for its ultimate objective the complete consumption of all of the uranium and thorium, not just the small quantity of the natural fissionable isotope of uranium.

Utilizing heat developed in reactors

Heat generated in a reactor core must be continuously removed by a coolant. In the pressurized water reactor, the coolant is high-pressure water. The high-pressure water transfers its heat through a heat exchanger to a separate water circuit to generate steam with which to operate the turbine generating plant.

Another type of reactor is arranged to boil the cycle water in the reactor core. This is the type of reactor which is under construction at the Argonne National Laboratory.

Some reactor cycles use liquid sodium or an alloy of sodium and potassium called NaK as fluid coolants. The liquid metal transfers heat to a water boiler of the heat exchanger type.

The use of liquid metal as a heat carrier requires special pumps in the coolant circuit. Some of these special pumps are driven by integral motors which are designed to operate with liquid metal present in the air gap. Other liquid-metal pumps are of the electromagnetic type in which a magnetic flux imposes a driving force on the pumped fluid in a manner closely resembling the generation of torque in the rotor of an induction motor. This type pump requires no moving parts or glands to seal-in the liquid metal.

One important group engaged in the development of a plant for the generation of electric power from a nuclear heat source is the Atomic Power Development Associates, Inc. Under the guidance of Walker L. Cisler, president of the Detroit Edison Company, the thirty-three member companies forming this management group have been active for several years in the development of a breeder reactor which will supply steam to a 100-mw turbine generating plant to be built in an area served by the Detroit Edison transmission lines.

The reactor will be of the heterogeneous type and its primary coolant will be liquid sodium. Circulated by centrifugal pumps, the sodium coolant will remove heat from the reactor core and blanket for transfer to the secondary coolant, NaK, through a heat exchanger.

In the secondary coolant cycle, pumps will circulate the NaK through a second group of heat exchangers to generate dry and saturated steam for the turbine at a pressure of 600 psi.

Surrounding the core of enriched fuel within the reactor will be the blanket comprised of a large number of replaceable elements containing the fertile material, which may be natural or depleted uranium or thorium.

Means for the remote-controlled removal of individual fuel and blanket elements for processing will be provided.

A system of shim rods and emergency control, or "scram" rods, will be provided for the control of the heat output of the reactor under normal conditions of load change or in the event of any conceivable emergency such as loss of power on the coolant pumps.

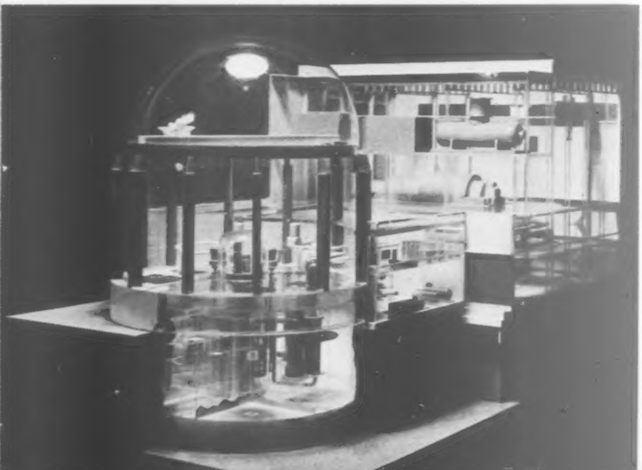
While the reactor is designed to be inherently self-regulating, all components containing fissionable or radioactive materials will be contained in a gastight shell. Adequate size and strength to contain all material released during a prompt excursion will preclude the possibility of radioactive material being released to the atmosphere.

The income necessary to support and operate the reactor company will be derived from two sources: the sale of steam to the electric generation facility, and from credit for the plutonium content of the used fuel elements, which will be retained by the weapons branch of AEC for the defense program.

If desirable to do so, the reactor can be refueled with the plutonium which it generates. In like manner, thorium 232 may be used in the blanket. After irradiation the thorium 232 becomes uranium 233, which also can be used as fuel.

Although a young industry, there is no question but that the nuclear heat source plant for electric power generation is with us to stay. This new source of energy is within our reach and is presently assessed as having a potential store of useful heat for human needs, including power generation, that is many times the corresponding amount of energy available from fossil fuel sources.

The scientific and engineering problems remaining to be solved in the development of nuclear heat source plants constitute a challenge to the imagination and ability of the scientists and engineers engaged in this work. The groups now engaged in the study of nuclear heat source plants are confident that power costs will be reduced as patterns of operating techniques are developed and the initial investment costs are lowered.



FOR FUTURE DEVELOPMENT by Atomic Power Development Associates, this is a model of the 100-mw electrical output power plant with breaker reactor heat source to be operated on the Detroit Edison System. **(FIG. 8)**

VERSATILITY CAST INTO NEW CT'S

by **GEORGE GALLOUSIS**
and
W. C. FARNETH
Allis-Chalmers Mfg. Co.
Pittsburgh Works

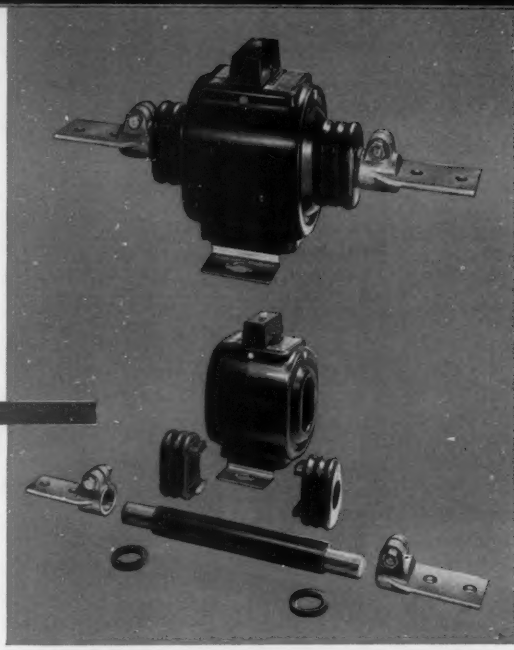
A new conversion kit makes it possible to change rating of 600-volt window-type current transformer to 5000-volt bar type.

CURRENT TRANSFORMER stocking problems are being simplified by increased versatility of design. Over the years reduction of weight and elimination of bulkiness have been the most important aims of designers. Now, however, obtaining wider use of single designs is also a major consideration.

An example of this type of thinking is the 600-volt insulation class window-type current transformer shown in Figure 1. By adding the insulated primary conductor, bushing inserts, two primary terminals, and necessary gaskets, the transformer becomes a 5000-volt bar-type unit.

The heart of this conversion idea is, of course, the transformer itself. This is a 600-volt insulation class window-type current transformer cast in an epoxy resin.* These units are now being manufactured in four current ratings: 200-5, 400-5, 600-5, and 800-5 amperes. All of these ratings are satisfactory for use at 200 percent continuous current in either indoor or outdoor applications.

A smooth metal mold is used to cast this transformer. In the casting process this mold is coated with release agents, and the transformer and its terminals are positioned and supported in the mold. The mold is then closed, the unit is thoroughly dried and a uniform mold and element temperature established. Meanwhile the epoxy resin is heated and brought to the same temperature as the mold. At the proper time a hardening agent is carefully and thoroughly mixed into the resin and the mold is filled. After the transformer is cured in an air-circulating oven and cooled to room temperature, the rating plate, secondary terminal board, and base are attached.



BAR-TYPE CT rated 5000 volts can be quickly assembled by adding the conversion parts to the 600-volt window-type CT. One transformer serves both voltage classes. **(FIG. 1)**

Designed conventionally this unit would have a bushing and case, which in turn require careful gasketing and sealing. Casting the unit eliminates sealing problems and results in a uniform and pleasing appearance.

Epoxy resin chosen

An epoxy resin was chosen for the casting material because this type of resin inherently has good adhesion to metal and ceramics, good mechanical strength, good dielectric properties, good resistance to temperature variations, low moisture absorption, low shrinkage during cure, and high resistance to solvents. Epoxies also can be easily and inexpensively cast. They are well suited for use in the design of higher voltage class and larger units. The design of these larger units naturally involves the solution of coil support and shrinkage problems, and holding the amount of resin used at an economical minimum. With the acquisition of practical "know-how" in the adjustment of the base resin formulation, the choice of a proper resin-to-filler ratio and casting process, practical mechanical designs of these larger, more complex units are being achieved.

Some interesting tests have been made to evaluate the epoxy cast transformer. One of the most important of these is the long-time test under actual operating conditions. Units have been in continuous operation at 200 percent rated current out of doors exposed to the sun and rain since October 1952. Test results of a representative 200-5 ampere unit are shown in Table I. Periodic testing of this unit and the other units shows no significant change in capacitance, dissipation factor, insulation resistance, and resin hardness. A steel bar fitted

* Epoxy resins are relatively new materials resulting from a condensation reaction of two basic components, each of which can be derived from petroleum. The two raw materials most commonly reacted to obtain these epoxy resins are epichlorohydrin and bisphenol. The product of this reaction may be modified by appropriate fillers, such as silica or quartz, and polymerized with a suitable hardening agent. Phthalic anhydride is the hardening agent used in this application.

ARTIFICIAL WEATHERING CHAMBER speeds tests to show effects of sun and rain on current transformer insulation. Epoxy resin insulation shows no change in characteristics. **(FIGURE 2)**

tightly into the transformer's primary opening was used as the primary conductor for this test.

With this long-time test method, years of testing are required to declare a transformer satisfactory. A quicker evaluation was obtained from thermal cycling, thermal aging, and artificial weathering tests.

For the thermal cycling test, units were maintained at a temperature of —30 C for 24 hours. They were then transferred to a 75 C atmosphere for 24 hours, after which they were maintained under room temperature conditions for another 24 hours. The duration of the complete test is 1008 hours, or 14 cycles. The same characteristics were measured for the thermal cycling tests as for the long-time roof tests and results indicate no appreciable change, as shown in Table II.

Similar results were obtained with thermal aging tests. The units were subjected to a temperature of 130 C for 1500 hours. This is approximately equivalent to 20 years of operation at 60 C. No significant characteristic change was noted. This test at 130 C for 1500 hours has as its basis the average copper rise of a 600-5 ampere current transformer operating at twice rated current. The rise of such a unit was found to be less than 30 C, thus making the average copper temperature of a unit operating continuously at twice rated current in a 30 C ambient less than 60 C. Assuming the ten-degree rule that the insulation life is halved for each 10 C increase in temperature, we find that 1500 hours at 130 C is approximately equal to 20 years of operation at 60 C.

Table III shows the results of the tests, presenting data on units both before and after thermal aging.

Insulation tested for weather

An artificial weathering chamber was used to determine the effect of sunlight and rain on the transformers. In this chamber, shown in Figure 2, transformers were operated at 200 percent continuous rated current for 1000 hours. Units were subjected to five times the maximum ultraviolet intensity of the sun by controlled sun lamps. "Rain" consisted of fresh tap water sprayed on the units for ten minutes of every hour. The test results again were satisfactory, showing no change in capacitance, dissipation factor, insulation resistance, or resin hardness.

Two other tests important in the evaluation of a material were dielectric strength at various temperatures and weight loss at elevated temperatures. Figure 3 is a curve of dielectric strength versus temperature whose points were obtained in accordance with ASTM Standard D 149-44. Sixty-cycle step-by-step one minute hold tests using two-inch diameter electrodes were performed on 80 mil thick six-inch-square samples. Tests at room temperature and 50 C were made in oil, inasmuch as creep occurred around the edge of the samples at these temperatures in air. All other test points were obtained in an oven in air. A comparison with the asphalt-impregnated paper curve points out the superiority of this material as dry-type current transformer insulation. The thermal stability of the epoxy resin used in these transformers is indicated by a curve of weight loss versus time at elevated temperature, shown in Figure 4. Subjecting the material to a continuous temperature of 170 C for 46 days resulted in a weight loss of only 1.8 percent.

TABLE I
Representative Long-Term Test Results
200-5 Ampere Unit

	Oct. 1952	Sept. 1954
Primary to Secondary and Ground		
Capacitance — Microfarads	82	54
Dissipation Factor — Percent	0.8	1.1
Secondary to Primary and Ground		
Capacitance — Microfarads	650	650
Dissipation Factor — Percent	3.8	0.9
Primary and Secondary to Ground		
Capacitance — Microfarads	630	603
Dissipation Factor — Percent	2.9	0.9
Durometer Hardness (Shore C Scale)	96	97

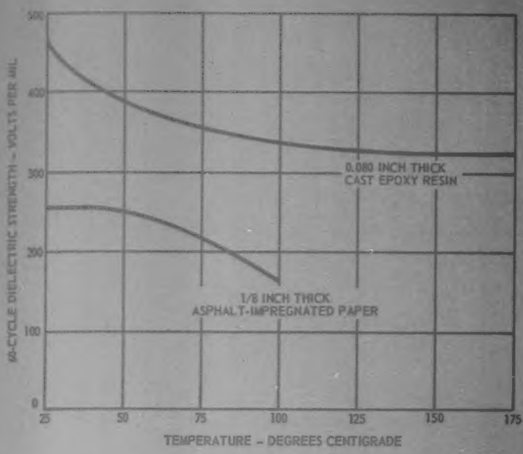
Resistance measurements, made at the same time as the capacitance and dissipation factor measurements, have been equal to or greater than 10 degree megohms through the test.

TABLE II
Thermal Cycling Test Results

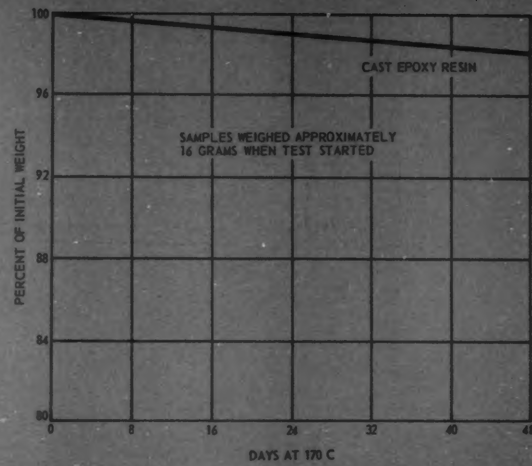
Unit	Number of Cycles	Capacitance* in Micro-microfarads	Dissipation Factor in Percent	Average Type C Shore Durometer Hardness
		Before Thermal Cycling		
A	0	408	1.3	97
B	0	456	0.5	97
C	0	385	3.2	97
		After Thermal Cycling		
A	14	405	1.9	98
B	14	450	1.2	99
C	14	385	3.8	97

Resistance measurements, made at the same time as the capacitance and dissipation factor measurements, were equal to or greater than 10 degree megohms through the test.

* Secondary to ground.



DIELECTRIC STRENGTH of cast epoxy resin insulation remains at high level even at elevated ambient temperatures. **(FIGURE 3)**



THERMALLY STABLE, epoxy resin insulation shows little reduction in weight when subjected to sustained high temperatures. **(FIGURE 4)**

Fire hazard considered

A rather spectacular test on these epoxy resin cast units shows that the transformer will not support fire. A torch applied to the units at a temperature of approximately 3500 C for 30 seconds caused burning, but after the torch was removed the resin burned slowly for only 8 seconds and then extinguished itself. Very little smoke and no irritating effects were observed. The resin was found to be charred to a depth of 3/16 inch. Beyond this depth the resin was still apparently solid. In addition, a number of units placed in an incinerator at 425 C showed no unusual behavior and no change in physical dimensions. The charred resin was easily chipped off, however.

An unusual quality control insulation test was used to check a larger number of production units. In Figure 5 are shown eight units immersed in a saline solution to a depth slightly below the secondary terminals. This solution has two functions: (1) When grounded it grounds the mounting feet and core, and (2) it acts as a primary conductor. Applying a 4000-volt sixty-cycle test voltage between the saline solution and the secondary terminals results in maximum information from a single testing operation. This test exceeds the 2500-volt sixty-cycle dielectric test between secondary and ground specified in ASA Standard C.57.13 and proves casting quality.

TABLE III
Thermal Aging Test Results

Unit	Capacitance in Micro-microfarads	Dissipation Factor in Percent	Average Type C Shore Durometer Hardness
Before heat aging			
D	353	2.1	92
E	270	1.5	92
F	319	1.5	90
After heat aging for 1500 hours at 130 C			
D	360	1.4	94
E	260	1.0	95
F	325	0.5	92

Resistance measurements, made at the same time as the capacitance and dissipation factor measurements, were equal to or greater than 10 degree megohms through the test.

* Secondary to ground.

Voltage class raised

The primary conductor shown in Figure 1 is a copper rod threaded at both ends and insulated by epoxy resin cast over its complete unthreaded portion. The primary bushings, which fit easily into the transformer's primary opening and through which the primary conductor passes, are also cast of epoxy resin. The installation of the copper primary terminal pads holds together the entire conversion assembly and raises the voltage level of the basic unit. Converted units withstand 5-kv insulation class, 60-cycle and impulse tests. They have also withstood the identical thermal cycling test to which the basic unit was subjected.

As molded current transformer designs are extended to higher voltage classes, similar means of broadening the useful range of each new type will be sought and fewer types of units will be required.

SALINE SOLUTION covers all but the secondary terminals in 4000-volt, 60-cycle production line insulation test. **(FIGURE 5)**

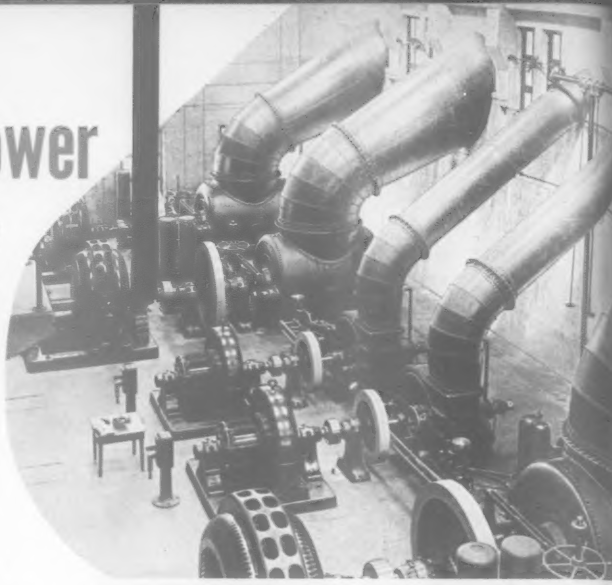
CRITICAL PERCENTAGE REDUCTION of silicon transformer-core steel requires sensitive high-speed control. Main mill voltage and reel tension regulator circuits for the new 4-high cold reversing strip mill at Crucible Steel's Midland Works utilize new high-gain magnetic amplifiers. Heavy-duty dc contactors shown on the mill's main control panel employ the arc-centering blow-out principle.


DUPLEX SCREWDOWN

American Hydro Power in the 20th Century

PART I

by **EDWARD UEHLING**
Hydraulic Department
Allis-Chalmers Mfg. Co.

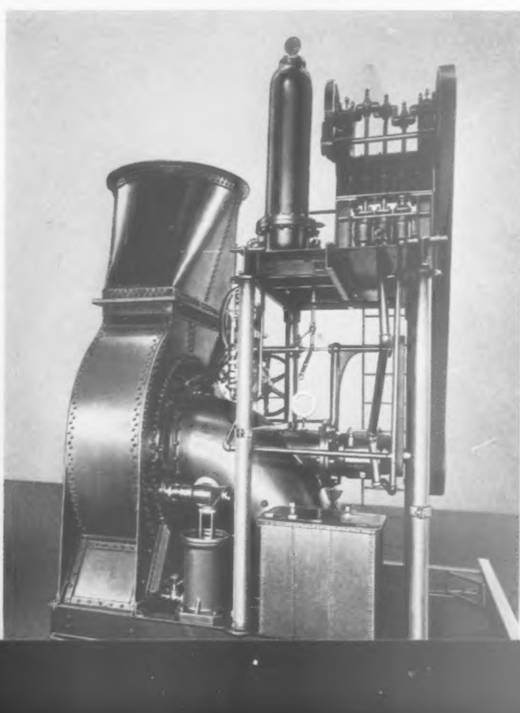


INSTALLED IN 1909 at the High Falls plant on the Peshtigo River, these hydroelectric units are typical of their day. **(FIG. 1)**

Significant engineering advances in Francis and propeller turbines are traced by the author in this two-part article, a sequel to his "Water Over the Dam."

ABUNDANT ELECTRIC POWER has become the symbol of achievement during the first half of the present century — an age of invention and progress unequalled in the entire previous annals of mankind. Today, water power development alone so far accounts for over 50 million horsepower in the United States and Canada.[1] Yet, when this century began, with a few exceptions, like the 5000-hp turbines (1895) at Niagara, water power in America was largely transmitted by ropes, belts, gears, and line shafts as mechanical power. America's first hydroelectric central station, built at Appleton, Wisconsin, in 1882, had scarcely been in existence eighteen years[2]. Producing only 12½ kw, it had a single dc generator, geared and belted to a small vertical turbine.

In the East, the American mixed-flow or Francis-type turbine had already evolved in a large number of makes.



THIS 1904 HYDRAULIC TURBINE had governor pressure tank and reciprocating oil pump on platform, jack shaft driven flyballs on quarter-turn discharge elbow, gate shaft operating cylinder and sump tank on base. **(FIGURE 2)**

However, units of more than 1000 hp were not common, specific speeds were low, namely around 68 or 69[3], and the heads utilized were usually quite modest.

For many years varieties of pivoted gates, operated by some kind of shifting ring, were being made by several companies, but cylinder gates were still quite common. Although the draft tube had been invented, only a few turbine builders understood or applied it as a means of gaining efficiency. For small single vertical units, a step-type thrust bearing below the runner, for taking the downward thrust, was in common use.[2]

Scroll cases had been used on many small water wheels for a short period after 1850. Later, however, "after being abandoned in the United States, the scroll was taken up by the Germans, and largely used for high-head Francis runners. Pfarr credits Voith with being the first to build an iron, spiral-cased, wicket gate turbine (1894). This type of wheel was much used in German and Swiss practice, and when high-head (Francis) developments began in this country, it was brought back from abroad."[3]

After the turn of the century, with the demand for increased electric power growing over the decades in leaps and bounds, and increased experience making larger and larger developments possible, new records in size, capacity, and head were continually being established by the major water wheel builders of this country. However, until about 1916, there were still only two principal types of hydraulic turbines being used—the Francis and the Pelton.

"Development of water turbine design has ever been progressive, more so during the 20th century than before, and the general tendency has been to improve the efficiency of all the component parts of the unit, besides simplifying and bettering the mechanical details of construction."[3] A few glimpses at some of these developments through the eyes of men who saw them will serve to tell the story.

"By about 1904, the spiral casing was in general use for high-head wheels. . . . Until reinforced concrete . . ." came into use shortly after 1900, making "the modern setting possible . . . it was much easier to build some kind of a

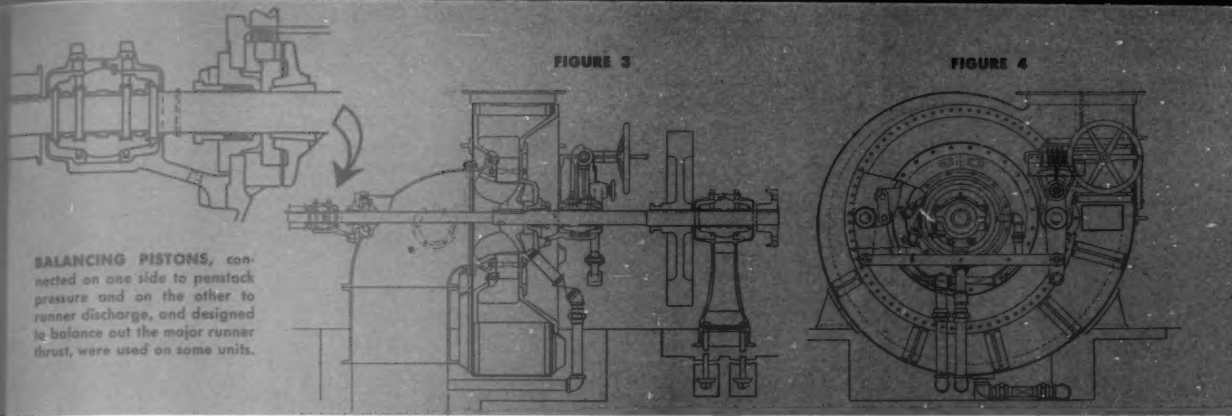


FIGURE 3 FIGURE 4

BALANCING PISTONS, connected on one side to penstock pressure and on the other to runner discharge, and designed to balance out the major runner thrust, were used on some units.

plate casing, usually circular in form . . . and let it go at that."[3] For some years, both preceding and after the turn of the century, a great many installations were of this so-called boiler-maker type, having steel-plate cylindrical casings with either top, side, or end inlets.

An American-built top inlet turbine made from Swiss designs, rated 1250 hp under 88-foot head, is shown in Figure 2. Water entered the runner through a cast-iron stay ring and governor-operated wicket gates. Still grinding out kilowatts (1955) is a very successful early (1909) utility company installation at the High Falls plant on the Peshtigo River in Wisconsin, see Figure 1. It consisted of five 1900-hp, 1000-kw, 80-foot head, 375-rpm twin horizontal top inlet *cylindrical* casing main units, and two 375-hp, 200-kw, 500-rpm single horizontal top inlet rectangular plate-steel spiral-type units.

A typical reinforced *rectangular*-type plate-steel scroll case turbine, such as would apply to the High Falls exciter turbines, is shown in Figures 3 and 4. Of special interest is the stub shaft, which had a balancing piston in addition to a ring thrust and steady bearing.

Matching turbine and generator speeds

One of the early methods, in both horizontal and vertical units, of producing the higher turbine speeds needed to match large capacity generator speeds was to mount two or more Francis runners on the same shaft. Hundreds of horizontal twin, quadruplex, sextuplex, and even eight-runner[2] units were in common use, see Figure 5. Typical of vertical open-flume arrangements were two 1909 triplex turbines, each rated 2000 hp under 18 to 27-foot head at 150 rpm, for the Hanford (Calif.) Irrigation and Power project, shown in Figure 6.

Gardner S. Williams, ASCE, mentioned[3] that in February 1905 he had designed for the Edison Sault Electric Company a hydroelectric plant[4] in which "the first low-head, *direct-connected vertical units* were installed. The design embraced concrete, *open-flume* scroll wheel-pits and concrete draft tubes, with roller bearings supporting the weight of the turbine and generator, and with conical covers over the (*Samson*) turbines. . . . This was the first hydroelectric plant, as far as the writer (Williams) knows, wherein the electrical equipment was made to conform to economical hydraulic requirements. In previous plants, the hydraulic machinery was subordinated to the electrical, and the inefficient horizontal installation of multiple-wheel units resulted."[3] Each of these turbines, see Figure 7, was rated 750 hp at 100 rpm under 16 to 17-foot head.

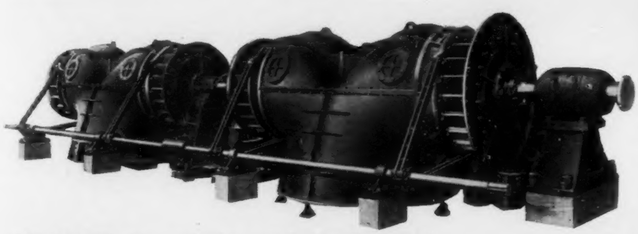
When much larger capacity single-runner units were built for low-head developments, complete scroll casings made of concrete were formed around them in the powerhouse foundation, similar to the settings at Keokuk.

Low-head power developed on the Mississippi

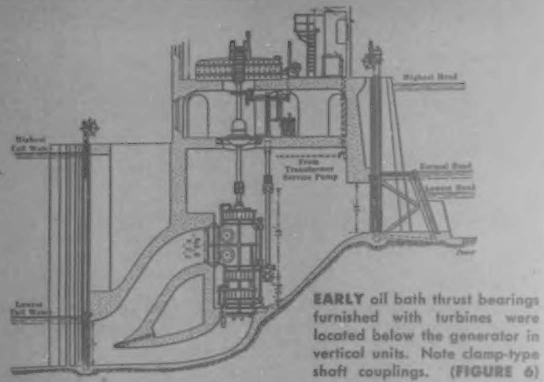
"At Keokuk, Iowa, the Mississippi River Power Company has erected and just put into operation (1913) a water power plant of distinguished proportions and noteworthy features with a power output by far the largest in the world. ". . . Generating equipment consists of 15 Francis-type turbines nominally rated at 10,000 hp (under 32-foot head) driving 7500-kw vertical dynamos. (See Figures 8 and 9.) The best practice and knowledge on water turbines of Norway, Switzerland, Germany, France, Italy, and America were drawn upon in designing these turbines, and, as a result, an efficiency of 86 percent by Holyoke test has been attained. . . ."[5]

"On the first twelve machines, the Standard combination roller and oil pressure bearing employed utilizes oil at 225 lb pressure, which normally keeps the 225-ton load lifted off the rollers. . . . Kingsbury thrust bearings are to be used for the remaining three machines. This new type of bearing requires oil circulation at only atmospheric pressure and introduces a low degree of friction. At 39 feet each unit will develop 14,000 hp, and at 20 feet, 6000 hp. This low-head condition was a factor in the selection of a turbine speed of 57.7 rpm. From the standpoint of American practice this is the first (large) plant to employ low-speed generators directly to single-runner turbines."[6]

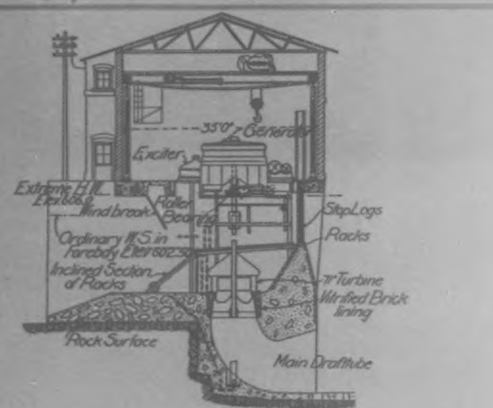
About the same time another low-head power development was taking place on the *upper* Mississippi, 13 miles above Minneapolis. This plant, at Coon Rapids, having Francis turbines of significant physical size, consisted of five units, each rated 2100 hp at 62 rpm under only 17½-foot head. They were two-bearing hydroelectric



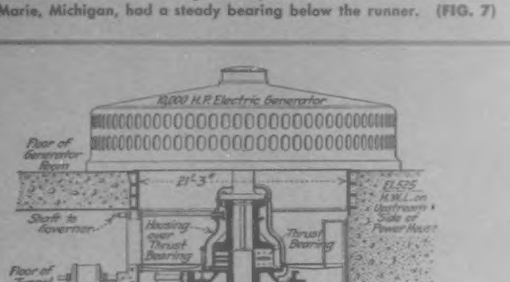
ONE OF FIVE, this quadruplex open-flume turbine, rated 3600 hp, 107 rpm, 25-foot head, was installed in 1912 on the Wisconsin River at Prairie du Sac. **(FIGURE 5)**



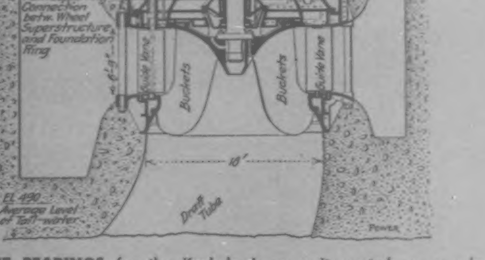
EARLY oil bath thrust bearings furnished with turbines were located below the generator in vertical units. Note clamp-type shaft couplings. (FIGURE 6)



VISIBLE in the above drawing, this open-flume Francis unit at Sault Ste. Marie, Michigan, had a steady bearing below the runner. (FIG. 7)



THRUST BEARINGS for the Keokuk, Iowa, units rested on a substantial stool supported by the turbine cover plates. (FIGURE 8)



CONCRETE SPIRAL CASINGS were used at Keokuk in 1913. (FIG. 9)

units with rotating elements carried on roller bearings above the generators.[7] In addition to the customary long turbine steady bearing on the cover plate, the stay-bolt type stay ring construction frequently used in low-head concrete scroll case settings of that period can be seen in Figure 10.

Smaller capacity low-head hydraulic turbines, in simple open-flume type settings, frequently had no outer stay ring. Instead, the stay bolts were moved inward and served as through-type wicket gate pivots, while tying the cover plate and discharge ring together. Wall struts were used for further rigidity. See Figures 11 and 24. Later, for open-flume units, a telescopic pit ring joint, shown in Figure 12, was developed. It provided a flexible, yet rigid, pit liner connection to the upper powerhouse structure, especially useful in obtaining a higher turbine setting for real low-head installations. Accessibility was greatly improved by this construction, which permitted the inspection, adjustment, and removal of the main turbine bearing without unwatering the flume.[8]

Cast-iron runners were in common use at this time. One very successful construction for low-head Francis-type runners combined cast construction with die-formed plate-steel buckets. These properly shaped plates were carefully set and molded in the foundry so as to enable a cast-iron runner crown to be cast integral with the buckets at the top, and a cast-iron discharge band to be cast integral with the lower ends of the buckets. This made a long-wearing combination having maximum size water passages.

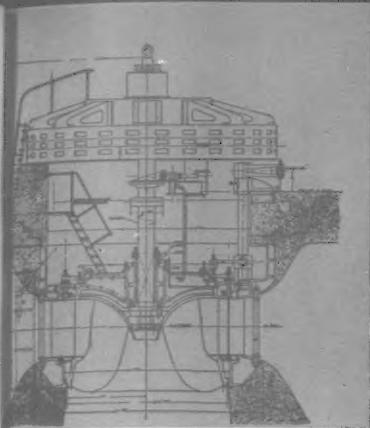
Francis turbines enter higher head field

By 1905 Francis-type turbines with cast spiral casings were being successfully applied to much higher head developments. In America, at least in the Far West, this field had been traditionally confined to impulse wheels of the Pelton type. Between 1905 and 1910, however, a considerable number of records, or near records, were being established by Francis wheels, both as to heads and capacities. Among these were two horizontal cast-iron spiral-casing units which were under construction in 1905. One was a 750-hp, 600-rpm turbine under 350-foot head for the Palmer Mountain plant in Washington State. The other, rated 5000 hp, 514 rpm, 320-foot head, was built for the Guanajuato Power and Electic Company in Mexico.

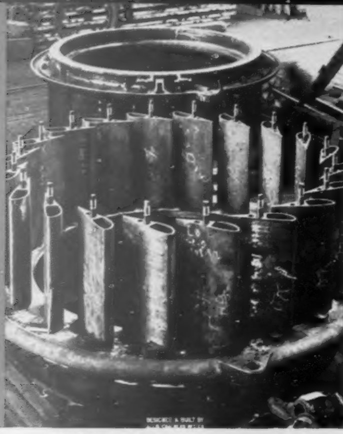
Records also, as to head and horsepower, were three single vertical cast-steel spiral-casing units shown in Figure 13, designed and built in 1906 for the Great Northern Power Company, near Duluth, Minnesota. Each was rated 13,500 hp at 375 rpm under 350-foot head.

Still another record for head made in 1906 was the 9700-hp, 550-foot head, 400-rpm single horizontal cast-steel casing unit for the Centerville plant of the California Gas and Electric Company, shown in Figure 14. By 1911 the head record was claimed for a 6000-hp unit under 670-foot head, built for the Michoacan Power Company in Mexico.

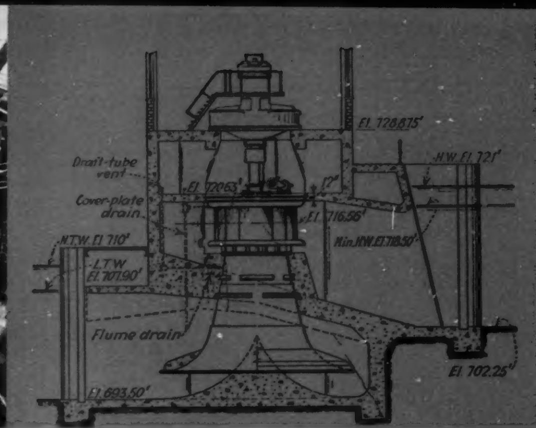
On the West Coast, about 1909 the Great Western Power Company installed four units on the Feather River in California. These were single vertical Francis turbines designed for 18,000 hp each at 400 rpm under 525-foot head, "now operating (1910) under 419 feet and stated to be the highest powered wheels in the world."[9]



VEL GEAR jack shaft drive for the governor, d regulating shaft-type wicket gate operation were used at Coon Rapids. (FIGURE 10)



WICKET GATES turn on stay bolt pivots in some vertical open-flume turbines. (FIG. 11)



PATENTED IN 1929, the H. J. Muth pit liner permitted higher settings for large, low-head open-flume installations. Note plate-steel *Hydraucone* draft tube. (FIGURE 12)

Among early capacity records for Francis-type turbines were two single-runner twin-discharge horizontal cast steel spiral casing turbines installed at the White River Development of the Pacific Coast Power Company, some 10 miles east of Tacoma. These units, see Figures 15 and 16, were each rated 18,000 hp at 360 rpm under 440-foot head.[10] The first load was carried during October 1911. Two duplicate units, but up-rated to 23,000 hp, were added later, the first in 1917 and the second in 1924.

The Tallulah Falls project, completed in 1913 by the Georgia Railway and Power Company, embraced a hydroelectric plant of 120,000 hp on the headwaters of the Savannah River in northern Georgia. This major water power project, located about 90 miles from Atlanta, was launched by men with faith in the future of our country, at a time when "the market for this amount of power was yet to be developed. . . ."[11]

Water compounded by a concrete dam 700 feet long and 110 feet high provides a supply basin from which the water flows through a 6670-foot tunnel to a surge basin, then through 5-foot steel penstocks leading to the turbine wheels. The initial installation consisted of five 17,000-hp (18,600 hp obtained), bronze runner, vertical Francis turbines operating at 514 rpm under 600-foot head. They were direct connected to 10,000-kva, 6600-volt, three-phase, 60-cycle generators and in 1913 comprised "the largest strictly high-head installation in the eastern half of the United States . . . using Francis-type reaction turbines . . . among the highest powered in the world."[12] "Selected cast iron was used for the scroll cases, which were cast in one piece and each case tested under 400 lb hydraulic pressure per square inch. . . . The normal draft head was 22 feet." The rotating parts were "carried by an oil pressure thrust bearing at the upper end of the shaft."[13]

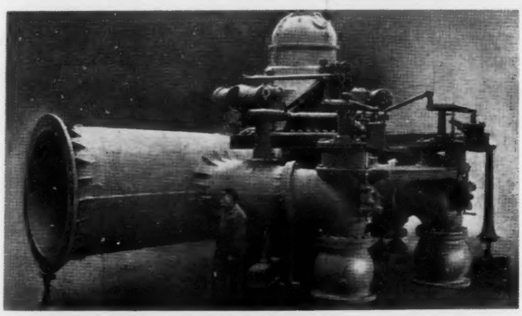
Plate scroll case invention is universally used

One of the greatest and certainly the most widely used hydraulic turbine inventions of the present century concerns the scroll case. "The 1912 invention and patent of W. M. White covering a steel-plate spiral casing of *circular* cross section, having *straight-line rolled sections,* opened up a great field of hydroelectric development. This invention not only made it possible to build more economical power plants of greater capacity, but formed the basis of all steel-plate spiral casings built since that time," according to Franz Schmidt, consulting engineer.[14]

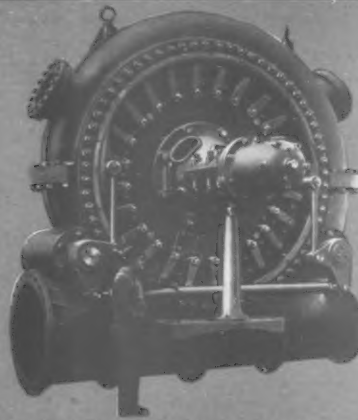
This invention permitted huge sections of spiral casings to be rolled, punched, and completely erected in the turbine manufacturer's plate shops. After dismantling and shipment, the sections were riveted together during assembly in the field. As welding techniques advanced, shop and field welding replaced riveting. This method of spiral casing construction has long since done away with most cast-iron and cast-steel casings, especially for large modern hydraulic turbines which would have been too large and expensive to build any other way.

The first use of this invention was made in 1912 in the fabrication of two vertical Francis units for the Tennessee Natural Development on the Nolenchucky River. Designed for an ultimate rating of 3200 hp each under 70-foot head, the casings had 9-foot inlet diameters. Their construction resembled very closely the design shown in the patent drawings, Figure 17.

As hydraulic turbines grew larger, many transportation and installation problems were encountered. For example, an erecting engineer for the Tennessee Natural Development installation recalled that "the two units were shipped by rail to Greeneville, Tennessee, and from Greeneville they were hauled to the erection site, a distance of some twenty miles, over an access dirt road. All of the equipment, both hydraulic and electric, was transported on wagons and pulled by mules and a steam threshing machine engine, see Figure 18. All the hydraulic parts, including volute casings (in sections), were lowered through the powerhouse roof section by means of a cable which spanned the river. . . . The first casing, after being sewed

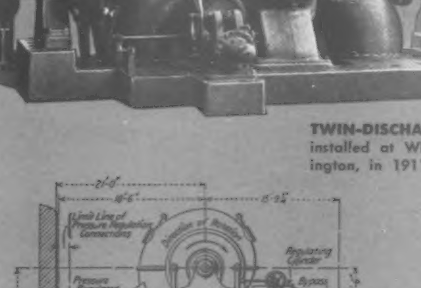


DEVELOPING 14,500 hp at 360-foot head, this 1906 unit had a 64-inch inlet, two-section cast-steel casing with two pressure regulators. Note oil pressure thrust bearing mounted on stool above turbine. (FIG. 13)

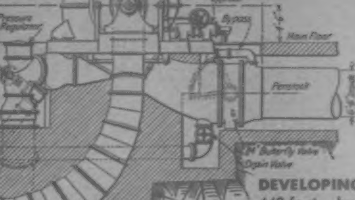


OUTSTANDING because of its 550-foot head, this Francis turbine was installed at Centerville, California, in 1906. Note the wicket gate shifting mechanism. (FIG. 14)

TWIN-DISCHARGE units were installed at White River, Washington, in 1911. (FIGURE 15)



DEVELOPING 23,000 hp at 440-foot head, each discharge elbow of the White River unit had its own plate-steel draft tube. (FIG. 16)



THE WHITE spiral casing ushered in an era of larger and more economical power plants. (FIGURE 17)

up to the speed ring, was riveted up with switch hammers and caulked in and out with hand tools."[14]

Water power helps industrial growth

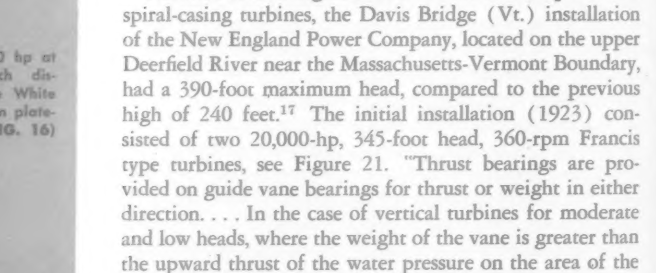
During the ensuing years, many large riveted plate-steel spiral-casing type hydraulic turbines, mostly in medium-head vertical units, were built and installed.

Among the large industrial groups to utilize and prosper in the very extensive use of water power were the textile mills and the paper mills.[2] Since the turn of the century, one of the most progressive groups to appreciate and develop large water power sites in both the United States and Canada is the ever-growing aluminum industry. Among these sites are now the largest developments in the world currently (1955) underway.

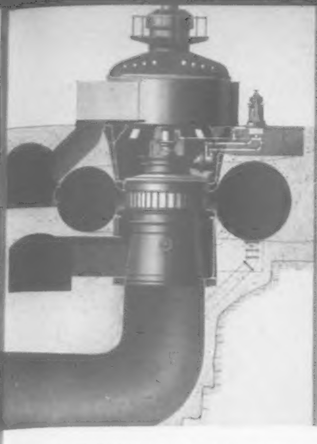
In 1916 the Aluminum Company in North Carolina placed orders for units developing 31,000 hp each under 188-foot head for their Narrows Development, and some of similar size for Cheoah. These units, among the most powerful of their day, were provided with unique telescopic draft-tube tops, as shown in Figure 19. In common use were governor flyballs driven by bevel gears, and a jack shaft from the turbine main shaft.

Industry was not alone in the progressive development of water power. The 37,500-hp, 213-foot head, 150-rpm single-vertical Francis type turbines at Niagara, see Figure 20, purchased in 1918, established a record and created much interest.[15] Also of record size and capacity were the steel scroll case units for the half million horsepower Queenston-Chippawa Canadian Niagara project.[16] The initial installation consisted of eight 55,000 to 60,000-hp vertical turbines operating at 187.5 rpm under 294 to 305-foot head. The first unit was placed in operation December 1921.

Referred to as a high head record for riveted plate-steel spiral-casing turbines, the Davis Bridge (Vt.) installation of the New England Power Company, located on the upper Deerfield River near the Massachusetts-Vermont Boundary, had a 390-foot maximum head, compared to the previous high of 240 feet.[17] The initial installation (1923) consisted of two 20,000-hp, 345-foot head, 360-rpm Francis type turbines, see Figure 21. "Thrust bearings are provided on guide vane bearings for thrust or weight in either direction. . . . In the case of vertical turbines for moderate and low heads, where the weight of the vane is greater than the upward thrust of the water pressure on the area of the guide vane stem, then the upward thrust bearing is omitted."[18]



HAULAGE OF EQUIPMENT from railroad to installation site was a major problem when the first circular section plate-steel spiral casings were installed. (FIGURE 18)



RUNNER REMOVAL and wicket gate access without disturbing turbine parts was a major advantage of the telescopic draft tube liner. **(FIGURE 19)**

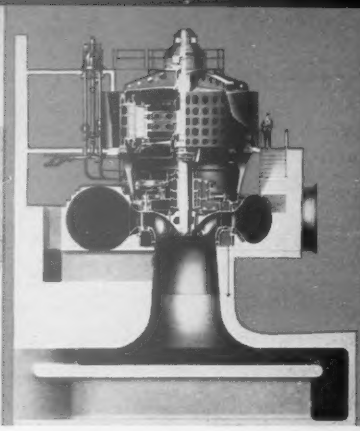
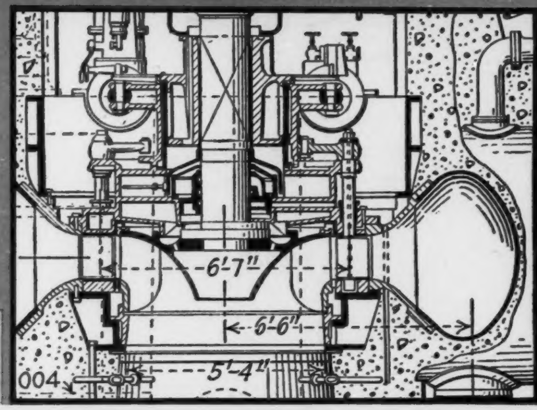


PLATE-STEEL spiral casing, cast-iron generator supporting barrel, *Hydraucone* draft tube, and direct-connected governor flyballs were combined in the Niagara unit. **(FIGURE 20)**



OIL WAS FORCED to the top of the bearing by a viscosity pump as the shaft of this Davis Bridge unit revolved. Note discharge ring liner below runner. **(FIGURE 21)**

By 1924 a large number of plate-steel spiral-casing type turbines had been installed, totaling well over one million horsepower. Here was an improvement in the art — a decided step forward, especially in the construction and installation of larger units.

Good draft tubes found to be essential

"With the development of large capacity units, a great deal of research was required in developing draft tubes to improve efficiency and operating performance. One of the outstanding developments was the White *Hydraucone* draft tube, which set forth some of the basic fundamental principles of regaining energy in draft tubes."[14] Years of thorough research resulted in the granting of a patent, to W. M. White.[19] This draft tube was formed of either concrete or plate steel. See Figures 22 and 12.

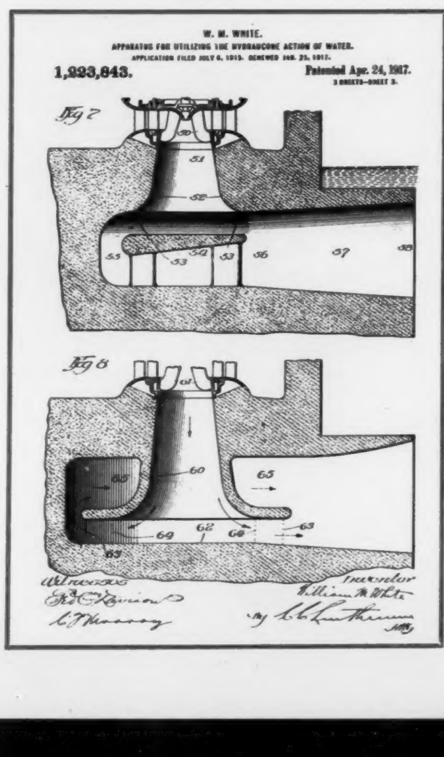
"In transition period of the 1920's when the simple conical draft tube was being replaced by tubes of greater efficiency or lower cost of construction, two new types of draft tubes were invented and the designs patented. . . . Contemporary with the White *Hydraucone* and competitive with it was the Moody Spreading Draft tube. Both tubes are somewhat complicated and expensive to construct. However, they are apparently very desirable draft tubes because our experience with turbines in these settings has been exceptionally good. . . ."[20]

"Most of the turbines installed during the past twenty years have been provided with elbow-type draft tubes . . . probably the simplest to design and easiest to install. . . . Draft tubes are designed to regain as much as possible of the energy remaining in the water after it has left the turbine runner."[20]

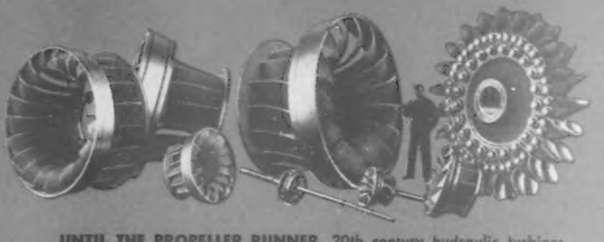
1910 heralds era of greater progress

Significant at this point are remarks made in early 1925. "To anyone who has followed hydraulic power engineering it must seem surprising that a machine, so highly developed as was the hydraulic turbine ten or fifteen years ago, should have suddenly entered a period of radical changes and encountered transformations in many of its essentials. The fact remains, however, that although practice in turbine design had become almost standardized in the period just prior to the (first) World War, the development of this art has taken on new life and has already been revolutionized in many aspects. The most striking changes have been those in runner and draft-tube design resulting in a remarkable increase in the specific speeds."[21]

The years 1910 through 1914 included such unprecedented improvements in the design of low-head Francis runners that this short period must not be overlooked. In reference to this, Prof. Floyd Nagler of Iowa State University, in his discussion of Safford's paper,[3] mentions that "specific (characteristic) speeds of 68 and 69 were attained in 1899 and 1897 by Smith-McCormick and *Samson* runners, respectively," whereas by 1914 specific speeds as high as 102 had been attained. He continues, "There can be little doubt but that Mr. Zowski was the leader in this latter achievement, and his wheels today (1922) represent runners of the highest efficiency and type characteristic manufactured by three of the largest producers of the American type of water turbine. The Zowski models, numbered I, II, III, IV, V, and VI, had specific speeds of 87.4, 92.8, 78.0, 90.0, 91.0, and 102, respectively, with maximum efficiencies of 87.2, 83.2, 89.2, 89.3, 90.1, and 90.7, respectively. In addition, his runners showed a flexibility hitherto unrealized."[22]

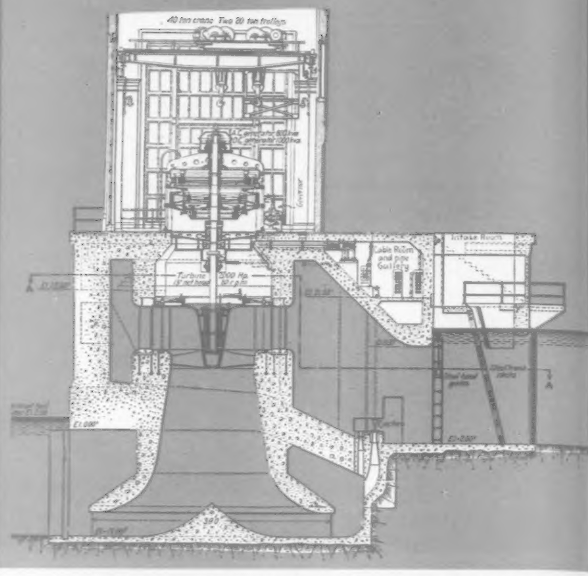


***HYDRAUCONE* DRAFT TUBES** helped to increase power and efficiency of hydraulic turbines, and were especially useful in low-head developments. **(FIG. 22)**



UNTIL THE PROPELLER RUNNER, 20th century hydraulic turbines were of two types, Francis (left) and Pelton (right). **(FIGURE 23)**

AMONG THE FIRST commercial applications of Nagler fixed-blade propeller units were these 100-hp, 8-foot head, 225-rpm turbines of 1916, shown in the shop awaiting shipment. **(FIGURE 24)**



A SYPHON SETTING for the large Green Island fixed-blade propeller turbines under 13-foot head reduced excavation. Note column-type stay ring and concrete *Hydraucone* tube. **(FIGURE 25)**

"During the months of September and October (1914) a number of tests were made at the Holyoke testing flume. . . ." Among the units were an improved *Samson* wheel and one (No. VI) designed by Zowski. The former, with a characteristic speed of 77.6 had "the unprecedented efficiency of 93 percent . . . the record of highest efficiency ever obtained in the Holyoke testing flume. . . . It was made possible only by . . . systematic . . . exhaustive research . . . over a period of about twenty years."[22]

Such improved wheels have been used over the years, especially in smaller capacity low-head turbines, except as superseded by the propeller turbine which followed closely on their heels.

Nagler fixed-blade propeller runner evolves

In 1907 and 1908 the late Forrest Nagler[23] was connected with some rather "extensive field work compromising the erecting, experimentally improving, and testing of some large-size axial-flow or screw pumps. This work concentrated all attention on a single type of hydraulic impeller for over a year, and it was only natural that impressions then formed should greatly influence his trend of thought in later work, which has been exclusively along hydraulic-turbine lines. At any event, the effect was such that the accepted form of reaction (Francis) runners, illustrated typically in Figure 23, then and still the basis of practically all low-head turbine design, seemed unnecessarily complicated and without logical justification from any hydraulic or mechanical standpoint. These ideas crystallized in 1913. . . . Models were made with the least possible delay . . . based on a straight radial blade, which offers the absolute minimum of wetted surface and of bending moment of the root of the blade. . . .

"Commercial installations of any considerable size were naturally approached with the greatest care. . . . The initial small plants designed in 1916 operated without any difficulties. . . . Up to date (1919) seventeen commercial runners of this type, varying from 80 to nearly 1000 hp in capacity, have been built or are building for a total of nine plants. Nine of these have been tested out thoroughly in place, with . . . characteristic speeds often over 200 under abnormal low-head conditions. See Figure 24.

"At the present time efficiencies equaling the records of reaction (Francis) wheels have not been reached, but they are being approached rapidly, and with the inherent advantage of better generator efficiency, equivalent combined results for the unit are only a matter of short time. . . .

"As to the nature of this new type of runner . . . it is undoubtedly a pure Jonval type,[2] although . . . his characteristic speeds seldom exceeded 20 or 30, as constrasted to the present 100 to 200."[23]

Safford[3] mentioned in 1922 that the Nagler propeller resembled several obscure 19th century wheels. One was the "Green Mountain" wheel, patented in 1860 by J. W. Truax, of Richford, Vt., which found limited use in his home state. The other was the "Austin" wheel, found in New York State. These wheels are shown in Figure 26.

Many fixed-blade propeller records established

Soon dozens of these fixed-blade propeller turbines were giving excellent accounts of themselves and were establishing new records. One of the most unique earlier installations was made in 1922, when four 156-inch diameter fixed-blade units for a head of only 13 feet were placed in service at the Henry Ford Green Island plant on the Hudson near Troy, see Figure 25. These units were each rated 2200 hp at 80 rpm and established a record for propeller turbine size. The wheels are direct connected to an unusual combination of double generators developing 800 kva of 4600-volt alternating current power and 1000 kw of 250-volt direct current. The direct current was required to drive motorized equipment in the plant,

alternating current was used for heating and heat treating. Since all machines were to be alike, double generators were provided. The ceiling of the huge concrete casing is considerably above headwater level. Consequently, ejectors were necessary to extract the air from the casing before they could be filled with water and the units started.[24]

At the Falls of the Ohio power plant, at Louisville, Kentucky, eight 180-inch fixed-blade propeller units, see Figure 27, each developing 15,500 hp at 106 rpm under 37-foot head, were installed during 1927 and 1928.[25]

Under full floodwater conditions, the head at this plant disappears entirely. Output records indicate that these units still produce some power with only a 6-foot head, possible only with propeller runners. An interesting comparison can be made between these units and the Francis runner which developed 14,000 hp under 39-foot head at Keokuk, see page 22.

Many other fixed-propeller records have followed. By 1932 there were five 30,000-hp, 120-rpm, 60-foot head units at LaGabelle, Quebec, and three 37,500-hp, 138.5-rpm, 66-foot head turbines at Seven Sisters in Manitoba.[26] Currently under construction are thirty-two units for the St. Lawrence Power Project, Barnhart Island Station, near Massena, New York. Sixteen of the units are for the Hydroelectric Power Commission of Ontario. The other sixteen for the New York State Power Authority are rated 71,000 hp each at best efficiency. Eight of these, having 240-inch diameter runners, will develop 79,000 hp at 94.7 rpm under 81-foot head.

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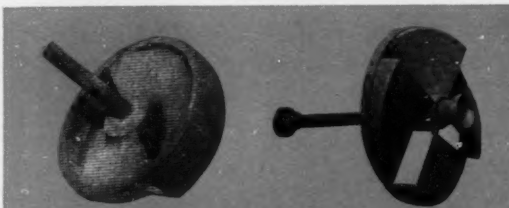
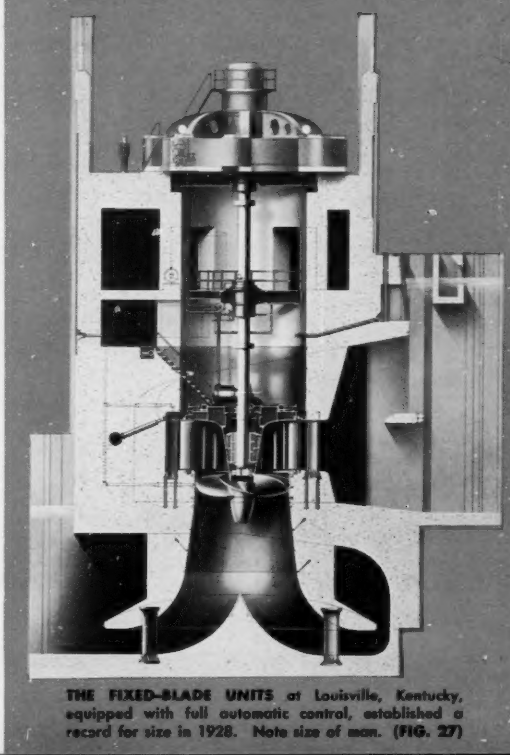


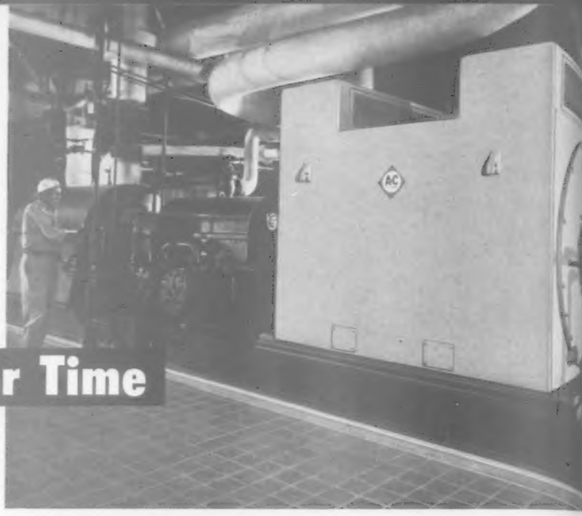
THE AUSTIN WHEEL (left) and the Green Mountain wheel (right) had big blade areas with rims. **(FIGURE 26)**



THE FIXED-BLADE UNITS at Louisville, Kentucky, equipped with full automatic control, established a record for size in 1928. Note size of man. **(FIG. 27)**

RESIDUAL VOLTAGE IN INDUCTION MOTORS

Influences Load Transfer Time



DRIVING A BOILER FEED PUMP in a modern power plant employing the unit system, this 3000-hp, 3600-rpm, 4000-volt induction motor typifies loads that may require transfer from one power source to another.

by **R. C. MOORE**
Motor and Generator Department
Allis-Chalmers Mfg. Co.

Transfer of high speed induction motor loads from one power source to another can be more readily accomplished if motors are designed for this service.

WHEN AUXILIARY DRIVE MOTOR LOADS in modern power plants are to be transferred from one supply source to another, the residual voltage present and its rate of decay in accordance with the open-circuit time constant of the drive motors become important considerations.

Most modern power plants employ the unit system in which each generator and its auxiliaries operate as a unit. The power source for auxiliary drive motors is either a mainshaft-driven auxiliary generator or a transformer connected to the generator leads. During the initial start-up of a unit, a separate source of power for the auxiliary drive is, of course, necessary. After the unit is placed in service, the alternate source of power available in the event of trouble in the normal supply is usually the power system itself, through a transformer.

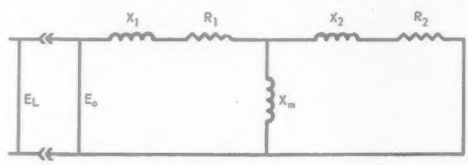
Transfer of auxiliary motor loads from one supply source to another may be made leisurely or rapidly, depending on conditions. A leisurely transfer can be made without power interruption by first paralleling the two sources. While the noninterrupting type of transfer is preferable, it is not always possible. For example, sources should not be paralleled if a phase shift difference exists between them. Determining whether transfer can be made leisurely or rapidly is not always left to a station operator. Because of this, many modern power plants have provisions for automatic load transfer from the normal source to an auxiliary bus under certain emergency conditions.

When the interrupted method of transfer must be used, the speed with which the load can or should be transferred from one supply to another is an important consideration. Too slow a transfer, with prolonged transfer time interval, will allow certain auxiliaries to slow down enough to jeopardize unit operation. On the other hand, rapid transfer may cause serious damage to some of the important auxiliaries.

Most of the motors driving important auxiliaries in power plants are of the squirrel-cage induction type. These auxiliary drive motors are becoming progressively larger as power plants grow in size, generator ratings increase, and steam pressures become higher. Induction motors of larger size, especially in the higher speed class, have longer open-circuit time constants than smaller machines and consequently are more difficult to transfer from one power source to another.

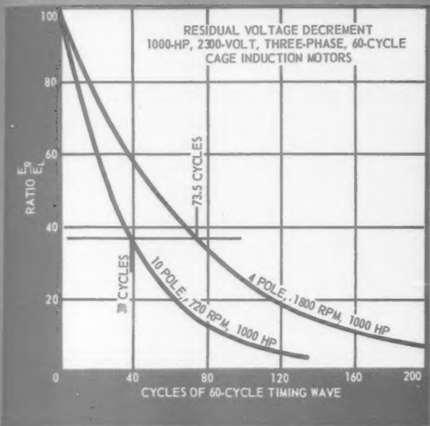
Residual voltage complicates motor load transfer

When an induction motor is disconnected from its power source, the voltage at the motor terminals does not drop to zero instantly. Since the motor's magnetic flux exists and the motor revolves, voltage will be induced in the stator winding. The magnitude of this voltage at any given instant after the motor has been disconnected from its source will depend both on the decay of flux and on the

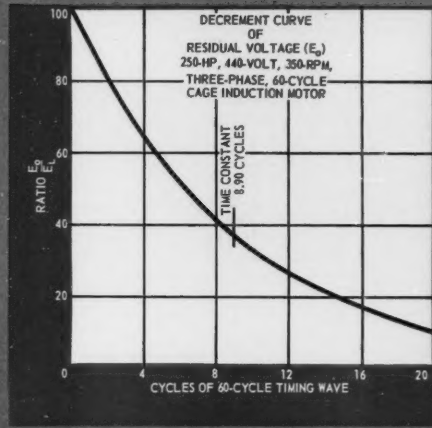


(FIGURE 1)

E_L and E_0 are line and residual voltage, respectively.
R_1 and R_2 are stator and rotor resistance in stator terms.
X_1 and X_2 are stator and rotor reactance in stator terms.
X_m is magnetizing reactance in stator terms.



HIGH SPEED MOTORS, because of their greater residual voltage, require closer control than lower speed induction motors when transferring from one power source to another. **(FIGURE 2)**



THIS RESIDUAL VOLTAGE decrement curve, plotted from information obtained from the test oscillogram of Figure 3, has time constant located at 36.8 percent of maximum voltage. **(FIGURE 4)**

decrease in motor speed. At the instant after disconnection, this voltage, E_o in Figure 1, will be very near the previous line voltage, E_L. The frequency of the residual voltage will correspond to the motor speed, since the magnetic flux is tied to the rotor.

If the motor is reconnected to another power source before the residual voltage has appreciably decreased, very large transient currents and torques can result. The result is similar to that obtained if a generator is synchronized while out of step with the line. The important considerations in transferring a motor or a group of motors from one supply to another are: (a) phase angle between the motor decaying residual terminal voltage and the new source voltage; and (b) the magnitude of the residual decaying voltage at the motor terminals.

Phase-angle switching

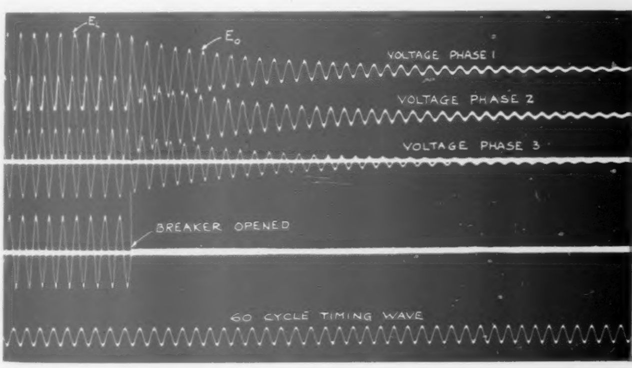
If a rapid transfer of auxiliary drive motors from one power source to another were arbitrarily made, damage to the motors would probably result except in those rare cases where phase displacement between the motor's residual voltage and the new supply voltage happened to be suitable. By appropriate relaying, however, it is possible to transfer a motor or group of motors from one supply to another rapidly at the instant when voltage phase conditions are most suitable for transfer. Tests have provided data which indicate that chance is removed by appropriate relaying, and transfer can be made with proper phase displacement even though the motor voltage, E_o of Figure 1, may not have dropped to zero.

Minimum switching voltage

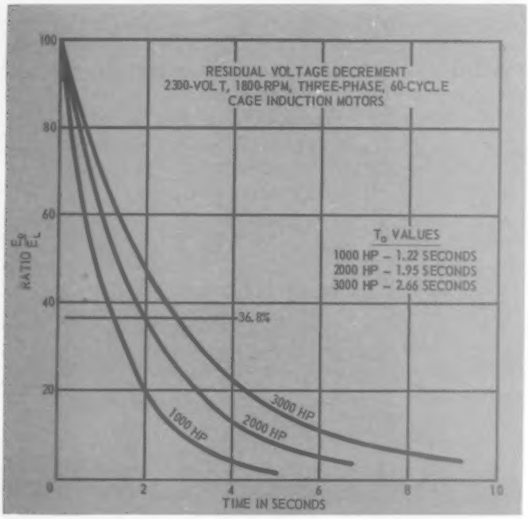
Motor residual voltage should be as low as possible before reconnecting the motor to a new source. The curves of Figure 2 indicate that, for a given time after disconnection, residual voltage will be greater on high speed than on low speed motors. The higher speed motors therefore present the greater hazard when switching from one power source to another before residual voltage has decayed to zero. While it is not essential that the residual voltage be zero before reconnecting the motor load to a new supply source, the amount of residual voltage that can be tolerated will depend on the motor characteristics and on operating practices.

Rotor transient at disconnection analyzed

At the instant the motor is disconnected from its supply, current ceases to flow from the source to the motor. However, in the closed rotor circuit of the motor rotor, see Figure 1, current will not drop to zero at once but will change to whatever value is necessary to maintain the motor flux at that time. At disconnection, therefore, the



DECAY of residual voltage from the opening of motor breaker is indicated by this oscillogram for a 440-volt, 250-hp, 350-rpm, three-phase, 60-cycle motor. **(FIGURE 3)**



HIGHER HORSEPOWER motors have longer time constants than smaller motors if other rating characteristics are equal. **(FIGURE 5)**

rotor flux is "trapped" and no longer moves along the rotor surface but is tied to it. The rotor flux then decays with time, and as it decays it induces a voltage which acts to sustain the slowly decaying rotor current. The voltage around the closed rotor circuit, diagrammed in Figure 1, can be expressed:

$$L_2 \frac{di2}{dt} + R_2 i_2 = 0$$

The solution of which is:

$$i_2 = Ae^{\frac{-R_2}{L_2}t} \qquad (1)$$

where

$i_2 =$ the instantaneous rotor direct current in amperes at time t.

$R_2, L_2 =$ rotor resistance and inductance in ohms and henrys per phase in stator terms.

$t =$ time in seconds.

$A =$ the initial rotor current at time $t = 0$.

$e =$ the base of natural logarithms.

In the exponent of Equation (1), the ratio $\frac{L}{R_2}$ is usually referred to as the time constant of the decaying current in the rotor circuit. Since the voltage induced in the stator winding is dependent upon rotor current and flux, the time constant $\frac{L}{R_2}$ also applies to the decay of the open-circuit voltage induced in the stator winding. Accordingly, the open-circuit time constant T_o of the induced stator voltage is $\frac{L}{R_2}$.

In the closed rotor circuit of Figure 1 it is apparent that $\omega L = X_m + X_2$ so that T_o can be expressed as:

$$T_o = \frac{X_m + X_2}{\omega R_2} \quad \text{(seconds)} \qquad (2)$$

where $\omega = 2$ times line frequency when X_m, X_2 and R_2 are magnetizing reactance, rotor reactance and rotor resistance, respectively, expressed in ohms per phase referred to the stator.

Open-circuit voltage decays gradually

The direct current in the rotor and the associated rotor flux of an induction motor are analogous to the rotor current and flux of a synchronous generator with direct current field excitation. At full speed the flux induces a voltage, E_o, in the stator windings which is frequently referred to as residual voltage. Its value, immediately after the motor is disconnected, is very nearly equal to the value of the previously applied line voltage, E_L. After disconnection, the residual voltage decays according to the open-circuit time constant, T_o of Equation (2). The rms voltage induced in the stator winding by the decaying rotor flux and current can therefore be expressed as:

$$E_o = E_L e^{\frac{-t}{T_o}} \quad \text{(rms volts)} \qquad (3)$$

If the elapsed time of t seconds is equal to the time constant T_o, then the value of residual voltage E_o is 36.8 percent of E_L, the initial or maximum value. The value of E_o in $0.693T_o$ seconds is 50 percent of its initial value of E_L. In another $0.693T_o$ seconds, the voltage will be 25 percent of E_L. Again in as many seconds, 12½ percent, and so on.

Calculated and test data of T_o

The calculation of T_o is of course very simple when the design values for insertion in Equation (2) are available. For example, calculations per stator phase for a 250-hp, 350-rpm, 440-volt, three-phase, 60-cycle cage motor of typical design show X_m to be 1.17 ohms; X_2, 0.0637 ohms; and R_2 at test temperature 0.023 ohms. Calculations according to Equation (2) show:

$$T_o = \frac{1.17 + 0.0637}{377 \times 0.023} = 0.142 \text{ seconds.}$$

Converted to cycles for a frequency of 60 cycles, the time constant T_o is 8.52 cycles.

A test oscillogram indicating residual voltage decay after the motor breaker was opened is shown in Figure 3. Since this test was made with the motor unloaded, the drop in motor speed for the short duration of residual voltage decay was negligible. To indicate the nature of voltage decay, rms voltage information was taken from Figure 3 and plotted as shown in Figure 4. The time constant T_o can be located on this curve at 36.8 percent of maximum voltage. If verification is desired, time constant can be readily calculated, since at 50 percent voltage the time in seconds is $0.693T_o$.

The larger the motor's horsepower, the larger the open-circuit time constant T_o, if other rating characteristics such as voltage and speed are equal. In other words, motor residual voltage "hangs on" longer for larger horsepower motors, other characteristics being equal. This is illustrated in Figure 5 by curves drawn for three horsepower ratings of 1800-rpm motors of efficient design. Open-

circuit time constant T_o is also affected by motor speed. The higher a motor's rated speed, the larger its time constant, other rating characteristics being equal. This is illustrated in Figure 2, where motors of the same horsepower but two different speeds are considered. Because of their high speed, two-pole motors have larger open-circuit time constants than comparable motors having more poles.

There can of course be a wide variation in values of T_o for different motor designs even for the same horsepower, speed, and other nameplate designated characteristics. Since motors in the larger sizes are usually designed to fit a specific drive, two motors apparently identical in all respects can and often do have entirely different time constants.

Control of T_o in design

If required, a motor having a low time constant can be designed, and Equation (2) indicates the factors involved when searching for a means to reduce T_o. Evaluating these factors, we learn that the value of X_2, rotor reactance, does not vary much in percentage value among motors of larger than NEMA sizes. If rotor resistance, R_2, is increased, T_o will be reduced, but so will motor efficiency.

Having eliminated these two factors as a means of reducing the time constant, the effect of reducing X_m, the magnetizing reactance, on T_o and other motor characteristics should be considered.

Magnetizing reactance is largely determined by the motor air-gap dimensions. An increase in air gap will increase the motor magnetizing current, decrease the value of X_m and lower T_o. However, not only is time constant reduced, but power factor is also reduced. The reduction in power factor for a 1250-hp, 3600-rpm, cage-type induction motor having double nominal air gap is shown in Figure 6. The decrease in open-circuit time constant T_o brought about by the air-gap increase is shown in Figure 7.

Two-pole motors are the largest single units among the auxiliary drives in modern power plants. Because they have large values for T_o, they have the greatest influence on the rapidity with which auxiliaries can be reconnected to an emergency power supply. Consequently, as high speed motors become larger and values of T_o increase, an increase in air gap may be desirable to reduce the value of T_o even at the sacrifice of some of the motor characteristics — mostly power factor.

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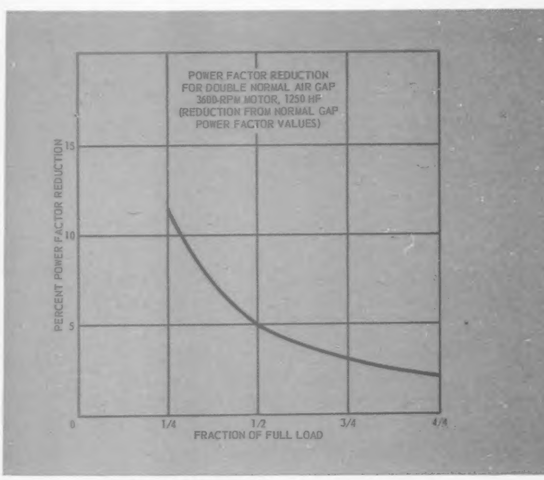
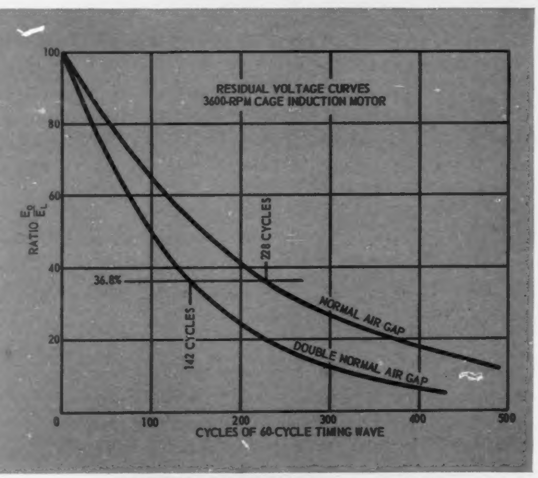


TIME CONSTANT can be reduced by designing increased air gap into an induction motor — some power factor reduction results. **(FIGURE 6)**



AMOUNT OF DECREASE in open-circuit time constant resulting from increased air gap is indicated by these curves. **(FIGURE 7)**

EVALUATING NEUTRAL REGULATORS

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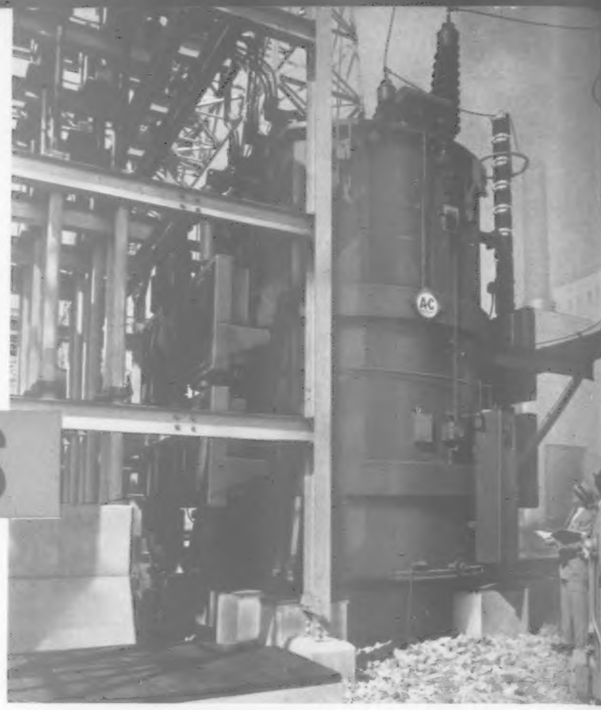


PROVISION FOR FUTURE application of a neutral regulator is often specified for large power transformers. The neutral end of each phase is accessible through 34.5-kv bushings of this 83,500-kva, Type FOA, 13.2 delta to 138-kv, GrdY generator transformer.

Neutral regulators provide good regulation at a substantial saving in initial cost for certain applications.

CONTROL OF SYSTEM VOLTAGE is usually accomplished with transformers having integral load tap-changing equipment, regulating transformers, or some combination of the two. While such equipment has proved satisfactory, neutral regulators have in many cases been overlooked. Frequently, neutral regulators will provide good voltage regulation at a considerable saving.

A neutral regulator, as the name implies, is connected in the neutral of a wye-connected, solidly grounded transformer bank. It may be connected in the neutral of the high voltage winding and excited from the low voltage winding in a two-winding transformer, or from the tertiary winding in a three-winding transformer. It may also be connected in the neutral of a wye-connected low voltage winding and excited from the low voltage winding, or from a tertiary winding if one is available. Figure 1 shows the winding arrangement and connections for a neutral regulator connected in the neutral of the low voltage winding and excited from the tertiary of a power transformer rated 115 kv GrdY — 69 kv GrdY — 12 kv delta.

Neutral regulators are separate winding devices, as contrasted with regulating transformers, which are autotransformer-type devices. Regulating transformers are self-excited and obtain their excitation from the voltage being regulated, whereas neutral regulators may or may not obtain their excitation directly from the voltage being regulated. Figure 2 shows the connection and winding arrangement of a regulating transformer used to regulate the low voltage winding of the transformer in Figure 1.

Insulation level is a factor

Neutral regulators should be considered where voltage regulation is required for existing transformer banks. If a grounded wye-connected winding is available, there is a good possibility that the use of a neutral regulator is feasible. The insulation level of the neutral end of a grounded wye winding should be checked against the values given in Table I to determine if the neutral is insulated sufficiently for the addition of a neutral regulator. The neutral ends of the wye-connected winding will not be at ground potential, since they will be connected through the regulating winding of the regulator to ground. When neutral regulators are used in windings 92 kv or higher, the transformer regulating winding must be insulated with 25-kv class or higher insulation. If existing transformers are single-phase, the neutrals of each phase are readily available, simplifying the connection between transformer and series winding of the neutral regulator. If the transformer is a three-phase unit, however, the neutrals of each phase are not as readily available. The neutral ends of each phase of the winding to be regulated must be brought out through bushings, to make them accessible for connection to the ends of the series winding of the neutral regulator. To use a neutral regulator with an existing three-phase transformer may or may not be practical.

Future units considered

The use of neutral regulation should also be considered where voltage regulation is not required at present but contemplated for some future time. The station should be

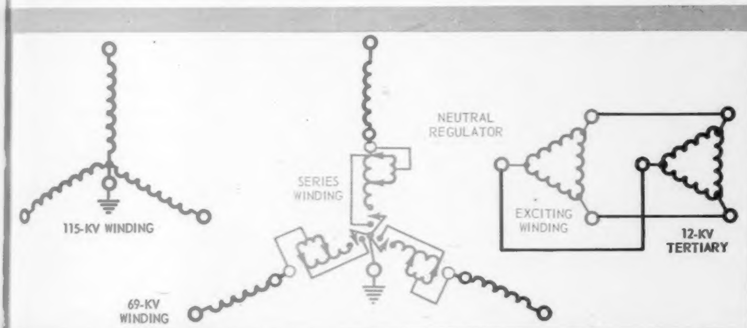
Line end insulation level of power transformer winding.		Insulation level of neutral end of power transformer winding and neutral regulator regulating winding.	
Voltage Class	**BIL**	**Voltage Class**	**BIL**
34.5	200	8.6	95
46	250	15	110
69	350	15	110
92	450	25	150
115	550	25	150
138	650	34.5	200
161	750	34.5	200
180	825	46	250
196	900	46	250
230	1050	46	250
260	1175	69	350
287	1300	69	350
315	1425	69	350
345	1550	69	350

TABLE I

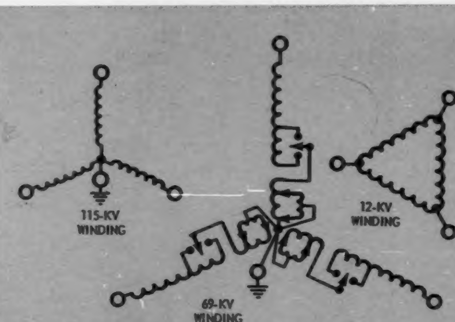
designed for the future addition of a neutral regulator. The neutrals of each phase of the transformer winding in which a neutral regulator will be connected should be properly insulated and brought out through bushings, or provision made for the future addition of these bushings. When these features are considered, a neutral regulator can be added with a minimum of time and effort.

Where voltage regulation is required at the time the transformer or substation is installed, it is usually more economical to include the voltage regulating equipment as an integral part of the power transformer. If a separate voltage regulating device is required, however, it is well to determine if a neutral regulating transformer can be applied. As an example, let us compare the various methods of obtaining voltage regulation for a 30,000-kva, Type OA, three-phase, 115-kv GrdY to 69-kv GrdY power transformer with a 12-kv tertiary for harmonics. The initial cost of a power transformer with plus and minus 10 percent load tap-changing equipment in the neutral of the 69-kv winding is approximately $185,000. Figure 3 shows a typical winding arrangement for this transformer. The initial cost of a similar power transformer with a separate 69-kv, plus and minus 10 percent regulating transformer in lieu of integral load tap-changing equipment is approximately $217,000. The initial cost of the same transformer with a plus and minus 10 percent neutral regulator connected in the neutral of the 69-kv winding and excited from the 12-kv tertiary is approximately $192,000. Figures 1 and 2 show the winding arrangement and connections for the neutral regulator and regulating transformer, respectively.

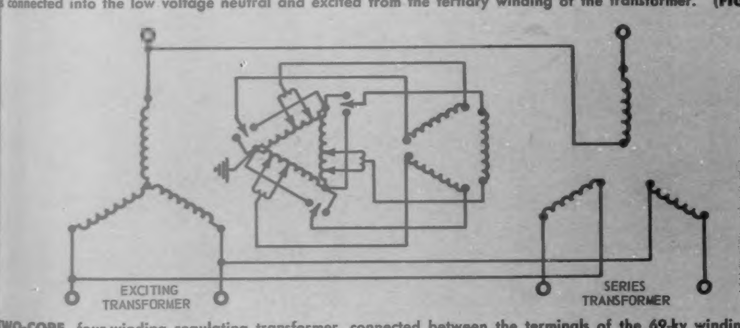
Figures 4 and 5 show the connection and winding arrangement of a single-core, two-winding neutral regulator. Figure 4 is used when the excitation is obtained from a delta connection source and 5 from a wye connection source. To obtain proper phase relationship between the voltage to be regulated and the excitation voltage, the exciting winding of the neutral regulator should be delta connected when the source of excitation is delta connected, and wye connected when the source is wye connected. The winding arrangements shown in Figures 4 and 5 are usually used where the excitation voltage is 15 kv or less and the winding to be regulated is 69 kv or less. Figure 6 shows a 25,000 circuit kva neutral regulator which is excited from a 46-kv wye-connected source. The winding arrangement is similar to that shown in Figure 5.



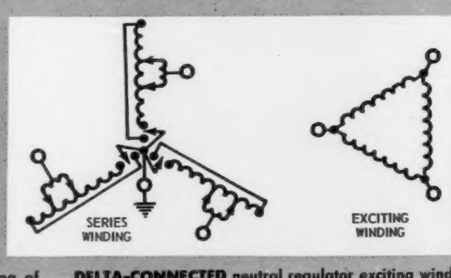
ONNECTION ARRANGEMENTS for different installations vary. In this arrangement the neutral regulator s connected into the low voltage neutral and excited from the tertiary winding of the transformer. **(FIG. 1)**



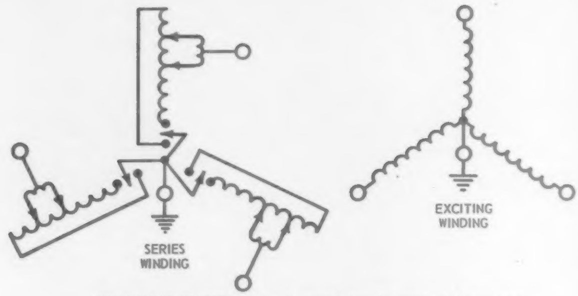
LOAD TAP-CHANGING TRANSFORMER usually provides most economical regulating means. **(FIG. 3)**



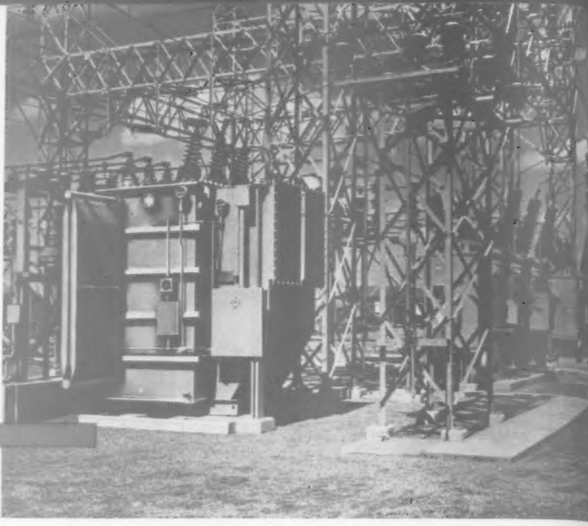
WO-CORE, four-winding regulating transformer, connected between the terminals of the 69-kv winding of he transformer in Figure 1 and its load, requires that no special connections be made between units. **(FIG. 2)**



DELTA-CONNECTED neutral regulator exciting winding is used with delta-connected source. **(FIG. 4)**



WYE-CONNECTED neutral regulator is excited from wye-connected primary, secondary, or tertiary winding of transformer. Neutral leads must be accessible. **(FIGURE 5)**



ZIGZAG, 46-KV WINDING of transformer bank serves as source for 2000/2500-kva, Type OA/FA-TLH, plus or minus 10 percent neutral regulator in southeastern substation. **(FIG. 6)**

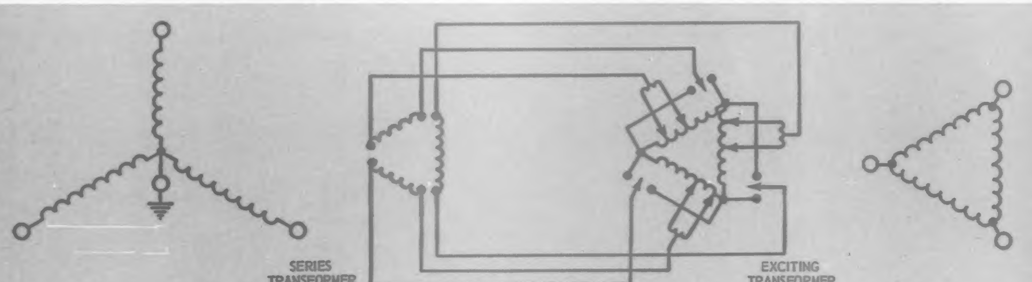
Figures 7 and 8 are two-core, four-winding neutral regulators. These units are normally applied where the excitation voltage is 25 kv or higher and the regulated circuit is 115 kv or higher.

Neutral regulators have limitations

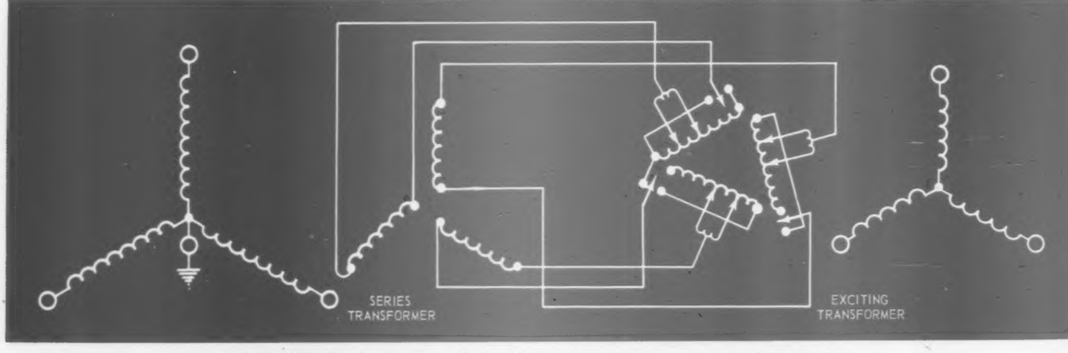
Although the neutral regulator, when applicable, usually has a price advantage over the standard regulating transformer, it has disadvantages. The neutral regulator can be used only for the application for which it was specifically designed. It does not have the flexibility of the standard regulating transformer, which can readily be moved to other parts of a given system. However, power transformers are seldom relocated.

In the application of neutral regulators, consideration must be given to the insulation class and availability of the neutral ends of the winding on which the regulator is to be connected. Unless the future use of a regulator was considered when the power transformer was designed, it may be difficult if not impossible to obtain voltage regulation with the use of a neutral regulator.

Although the application of neutral regulators is somewhat limited, they should be considered whenever conditions permit, since the saving in initial cost is usually substantial enough to justify their use.



TWO-CORE, FOUR-WINDING neutral regulators are used where the excitation source is 25 kv or more and where the regulated voltage is at least 115 kv. **(FIGURE 7)**



FOUR-WINDING neutral regulators, like the two-winding units, have delta exciting winding for delta source and wye exciting winding for wye source. **(FIGURE 8)**

F. C. Ludington, Manager
Hawley Works
C

ALLIS-CHALMERS
POWER
Transformers

600-Kv Transformer Provides Answer To Utility Problems

This is the highest voltage commercial-type power transformer ever built. Successful completion of tests shows that system designers now have a proved means for raising transmission voltages far beyond present levels. These tests also prove the quality of new insulation techniques developed by Allis-Chalmers.

After completion of all test operations, this transformer was added to the extensive facilities Allis-Chalmers maintains for power transformer research. It provides a means for practical study of new developments like the switching surge application outlined on the preceding pages.

Acoustical Research, Too

Allis-Chalmers research continuously takes into consideration problems of utility engineers as well as problems of product improvement. An example is the introduction of the Carrollville Acoustical Proving Ground last year. This outdoor sound facility, covering ten acres, provides utilities with a unique opportunity for finding a practical, economical solution to sound problems.

Information on any of these Allis-Chalmers developments is available by calling on a nearby Allis-Chalmers office. Or write Allis-Chalmers, Power Equipment Division, Milwaukee 1, Wisconsin.

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